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AN ANALYSIS OF HUMAN CAUSAL FACTORS IN UNMANNED AERIAL VEHICLE (UAV) ACCIDENTS

December 2014

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13. ABSTRACT (maximum 200 words)

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The results of this study reveals that among 287 causal factors attributed to 68 accidents, 65 percent of the factors were associated with humans. Moreover, this study also discloses that the rater who categorizes the factors can differently observe, understand, and interpret the findings of mishap investigation; thus, human error may even impact the categorization phase due to the rater's perception. The research concluded that even though HFACS carried out its functionality well, further study is needed to conduct intense statistical analysis with unlimited data and to validate HFACS with more case studies and various raters.

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AN ANALYSIS OF HUMAN CAUSAL FACTORS IN UNMANNED AERIAL VEHICLE (UAV) ACCIDENTS

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TABLE OF CONTENTS

LIST OF FIGURES

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LIST OF TABLES

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LIST OF ACRONYMS AND ABBREVIATIONS

AAIB	Abbreviated Accident Investigation Board
AB	Air Base
AFB	Air Force Base
AGL	Above Ground Level
AGM	Air-To-Ground Missile
BDA	Battle Damage Assessment
CAS	Close Air Support
CS	Control Station
CCP	Coordination, Communication, and Planning
CRM	Crew Resource Management
DGPS	Differential GPS
DOD	Department of Defense
EO/IR	Electro-Optical/Infrared
EW	Electronic Warfare
FTU	Formal Training Unit
GCS	Ground Control Station
GPS	Global Positioning System
HALE	High Altitude, Long Endurance
HDD	Heads-Down Display
HFACS	Human Factors Analysis and Classification System
HTPC	Heated-Throttle Plate
HUD	Head-up Display
IMC	Instrument Meteorological Conditions
INS/GPS	Inertial Navigation System/Global Positioning System
IR	Infrared
LOS	Line of Sight
LRE	Launch and Recovery Element
MALE	Medium Altitude, Long Endurance
MC	Mishap Crew

MC1	Mishap Crew #1
MC2	Mishap Crew #2
MP	Mishap Pilot
MP2	Mishap Pilot #2
MRPA	Mishap Remotely Piloted Aircraft
MSL	Mean Sea Level
MSO	Mishap Sensor Operator
NAV	Nano Air Vehicles
NBC	Nuclear, Biological, or Chemical
NM	Nautical Miles
NPS	Naval Postgraduate School
OEF	Operation Enduring Freedom
PIC	Pilot in Command
SAR	Synthetic-Aperture Radars
SATCOM	Satellite Communication
SIGINT	Signals Intelligence
SOP	Standard Operating Procedures
T/N	Tail Number
UA	Unmanned Aircraft
UAS	Unmanned Aircraft Systems
UAV	Unmanned Aerial Vehicle
VPP	Variable Pitch Propeller
WCA	Warning, Caution, and Advisory

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I. INTRODUCTION

For several years, Unmanned Aerial Vehicles (UAVs) (also known as drones), though unpopular, have been improving. They are regarded as a fundamental part of major tactical and strategic systems on the modern battlefield (Miller, 2013). The increasing popularity of UAVs as a force multiplier in active combat, however, has increased the frequency of UAV accidents, and this is no less true in the Turkish Armed Forces. UAVs are inherently similar to manned aircraft, yet mishaps involving UAVs differ significantly from manned aviation accidents. Such unmanned mishaps were regarded as ground accidents within the U.S. Army in the past. However, they are now considered as having both a ground and aviation component. (Tvaryanas, Thompson, & Constable, 2005). "Recent research demonstrates that both aviation and ground accidents have three major components: human, materiel, and environmental factors" (Manning, Rash, LeDuc, Noback, & McKeon, 2004, p. 3). Among them, human-related factors are an important cause for the increase in the frequency of UAV accidents.

Chapter I introduces the study. First, we discuss the increasing popularity of UAVs and emerging mishap rates associated with that trend. Second, we provide a brief summary of the goals of our study on this topic. Third, we pose several research questions on the topic, discuss the importance of UAVs, and address the need to minimize accident rates. Finally, we outline our research scope and conclude with a project overview.

A. OBJECTIVES OF THE PROJECT

UAVs are widely used in many fields such as military and intelligence (reconnaissance and close combat support); national security (policing and border patrol); and environmental, emergency response, and infrastructure (storm and weather monitoring, search and rescue, and damage assessment in natural disasters) (Deloitte, 2012). To increase the effectiveness of UAVs in these fields, the Turkish Armed Forces need to:

- Investigate UAV mishaps, analyzing each one for causal factors.

- Analyze the effects and the results of some specific UAV accident cases and their data in the U.S. military units to understand the effect of human factors.

- Minimize the possibility of UAV accidents that Turkey may confront within the near future, while increasing the number of UAVs in the Turkish Armed Forces inventory.

- Demonstrate the importance of human components in the operation of unmanned aircraft systems by means of HFACS.

- Analyze sample cases to determine the possible rating/coding discrepancies during investigation process by using HFACS.

The issues listed above will help us to identify the role of human factors in UAV accidents and lead us to seek ways to prevent from human-caused mishaps.

B. RESEARCH QUESTIONS

To better understand human causal factors in UAV accidents, and to find ways to prevent accidents stemming from human errors, we will focus on the following research questions.

- What common factors are related to humans in the U.S. Navy UAV accidents, how can the discovery of these factors shape the future applications of safety measures?

- What kind of analytic approach can be used to analyze human factors on UAV accidents?

- Is there any coding discrepancy among rater/mishap investigators while interpreting the findings of causal factors UAS accidents?

- How can Turkish Armed Forces benefit from the findings about the role of human factors in UAV mishaps?

C. SIGNIFICANCE

Despite the fact that UAVs have only recently received public attention, they have a long history. The history of UAVs extends to the beginning of aerial warfare and the first manned flights in the battlefield. The earliest cited military employing unmanned aircraft was Austria in the mid-19th century. "The aircraft attacked the Italian city Venice by using balloons laden with explosives." (Miller, 2013, p. 1). Even if balloons cannot be considered the pure ancestors of the UAV; the concept was promising enough to inspire flying unmanned vehicles in the battlefield after the invention of the winged aircraft (Miller, 2013).

The inventory of UAVs has been on the rise in most military services in recent years, and flying unmanned systems is not without risks. Moreover, despite advantages over conventional manned aircraft in decreasing human loss, unmanned flying requires significant financial resources to maintain continuous operations. Given the popularity and increase in UAVs, crashes have been reported worldwide. Causes for such accidents are related to material, environmental, and human factors and many studies have been conducted to reduce the effects caused by these factors. Of importance are the human factors. Our argument is that if we place greater emphasis on the human factors, we have a greater chance of mitigating the risks and challenges associated with human error in mishaps. In addition to the quality of training, crew synergy, and situational awareness, human factors include fatigue and problems associated with workload and adaptation (Manning et al., 2004). It is very important to know human-related causal factors to reduce costs and increase mission effectiveness. Being aware of the abilities of the system and tackling the hindrances to its pace of technological progress, will widen the fields of UAV usage and effectiveness.

D. RESEARCH SCOPE

UAVs can be categorized in terms of their functions such as reconnaissance, combat, and logistics, or by their range and altitude such as NATO type 10,000 ft. (3,000 m) altitude, up to 50 km range, Tactical 18,000 ft. (5,500 m) altitude, about 160 km range, medium-altitude long-endurance (MALE) up to 30,000 ft. (9,000 m) and range over 200 km and high-altitude long-endurance (HALE) over 30,000 ft. (9,100 m) and indefinite range (CNBC, 2014). This project focuses on the MALE type UAVs because of Turkey`s advancements in this type. A medium-altitude long-endurance UAV (MALE UAV) can fly 24 to 48 hours, and has state-of-the-art electro-optical payloads that put it on the forefront in the UAV market. The U.S., South Africa, Israel, and Turkey are the leading countries in this market.

A limited number of foreign-made UAVs have been used in Turkey for a long time. The first domestically produced Anka, medium-altitude, long-endurance class UAV is expected to be ready in 2016. All the drone systems will be delivered to the Turkish Armed Forces by 2018 (Raufoglu, 2014). Additionally, two other national tactical drone programs are proceeding at high speed. Procurement officials expect deliveries of both the Bayraktar and the Karayel UAVs to begin in 2014 (Bekdil, 2014). With these programs, Turkey will have a significant number of UAVs in the near future. To manage the increasing number of UAVs efficiently in the Turkish Armed Forces, an analysis of previous accidents can offer feedback to decrease high costs arising from these accidents.

This project discusses human causal factors on UAV accidents by using a systematic approach called Human Factors Analysis and Classification System (HFACS). Results will help identify the mishaps that may occur with an increase in the number of UAVs in Turkey, and will provide insight for better optimized and more effective UAV flights.

E. PROJECT OVERVIEW

The project will be organized into six chapters. Chapter I will be the introduction. It will describe the problem and objectives of the analysis. Chapter II will define some terms inherent to the system and discuss the literature review of UAV accidents. It will also focus on operational fields and the classification of UAVs. Chapter III will provide information about the development of HFACS and its application in aviation. Chapter IV will analyze the data gathered about UAV accidents and compare the findings to reach a final decision on the role of human beings in the mishaps. Chapter V will analyze sample case studies to identify possible categorizing discrepancies among rater / mishap investigators during interpretation of the UAS accident findings. Finally, Chapter VI summarizes the overall findings and presents recommendations for handling the rise of the UAV accidents.

II. UAS OVERVIEW AND LITERATURE REVIEW

A. INTRODUCTION

UAS technology has progressed during the past several decades. Military organizations around the world have been using them increasingly for the last 10 years (Lum & Waggoner, 2011). In the United States, from 2005 to 2011, the increase in UAV usage is approximately six-fold; about 100,000 flight hours to 600,000 in the Department of Defense (DOD). At the same time, the DOD boosted its UAS budget from $1.5 billion in 2005 to $6 billion in 2012 (Waraich, Mazzuchi, Sarkani, & Rico, 2013). Some researchers have determined that there are more than 10,000 UASs flying world at any given time. In 2010 in Afghanistan and Iraq, at least 38 UASs were in the air continuously (Waraich et al., 2013).

Furthermore, the unmanned aircraft category is quite diverse. Aircrafts' manufacturing range changes in size from small, which are capable of being hand-launched to large like transport aircraft, in weight from a few kilograms to more than 12,000 kg. They have different altitude and endurance capabilities as well as fixed and rotary wing types (Hayhurst, Maddalon, Miner, DeWalt, & McCormick, 2006).

With an increase in usage and diversity of unmanned aircraft, there is also brings an increase in mishaps and accident rates. We review studies that have sought to find the causes of these mishaps and accidents. Before reviewing the literature though, it is necessary to know the terminology, elements, types, application areas, and advantages of UAVs as well as people's perception about UAVs. Information provided here will help familiarize the reader to unmanned aircraft systems.

B. DEFINITION

Nowadays, unmanned systems and the terminology associated with their development are changing rapidly. Many terms are used to refer to unmanned aircraft systems such as unmanned aircraft (UA), unmanned aerial vehicles (UAV), and Unmanned Aircraft Systems (UAS). Historically, UAVs were considered autonomous or remotely piloted aircraft that could carry miscellaneous payloads like Electro-Optical/ Infrared (EO/IR) cameras, Synthetic-Aperture Radars (SAR), Electronic Warfare (EW) and Signals Intelligence (SIGINT). These types of payloads have helped missions to be more effective and convenient. Then, this view changed as authorities realized that the aircraft is not the only element in the unmanned aircraft system. Other elements are also equally important for the system's sustainability and persistence.

The FAA (Federal Aviation Administration) describes UAS and UA with the following definitions:

> A UAS is the unmanned aircraft and all of the associated support equipment, control station, data links, telemetry, communications and navigation equipment, etc., necessary to operate the unmanned aircraft (FAA, 2014).
>
> The UA is the flying portion of the system, flown by a pilot via a ground control system, or autonomously through use of an on-board computer, communication links and any additional equipment that is necessary for the UA to operate safely. The FAA issues an experimental airworthiness certificate for the entire system, not just the flying portion of the system (FAA, 2014).

C. WHAT COMPRISES AN UNMANNED AIRCRAFT SYSTEM (UAS)?

Both civilian and military unmanned aircraft systems include an unmanned aircraft, the human element (UAV operator, payload operator, flight technician), payload (EO/IR, infrared camera), control elements (autopilot and ground control stations), and data link communication (line-of-sight, satellite). Additionally, a military UAS may also include some specific elements such as a weapons system platform and some military related payloads such as SAR, EW, and SIGINT. Figure 1 (Barnhart, 2012) illustrates the various elements that contribute to a UAS.

Although it is sometimes ignored, the human element is the most prominent factor in this complex system because it is the integral piece and is necessary for running the UAS. Without the human element, it is impossible to handle emergency situations, execute emergency procedures, and navigate the UA to a safe location.

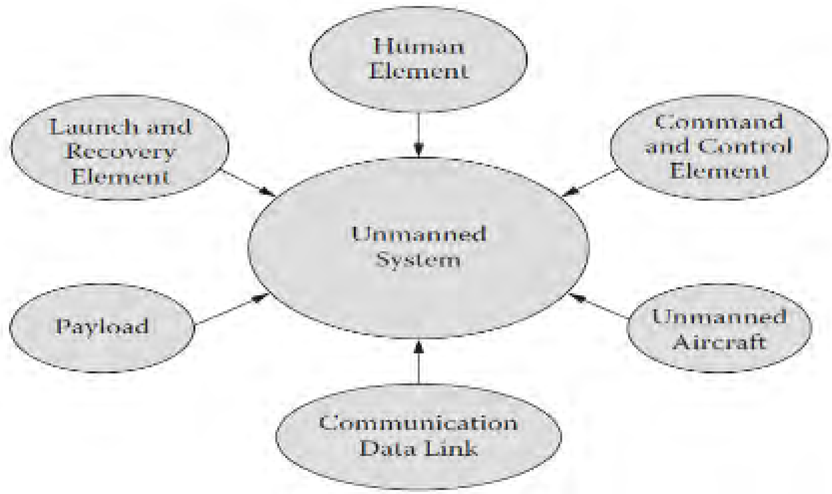

Figure 1. Elements of unmanned aircraft system (from Barnhart, 2012)

1. Human Element

In unmanned aircraft systems, the human element involves crew members, maintenance technicians, and those who assess video and images (generally intelligence analysts and decision makers). We will focus on the flight crew to analyze UA accidents. UAS crews generally consist of UA operators and payload operators, but in some countries like Turkey, Control Station (CS) technicians also serve as crew members during all phases of the flight. We define each crew member's role here, and provide examples of their duties (Hayhurst et al., 2006). Figure 2 shows UV operator and Payload operator performing their task during operation.

UA operators: The person who operates the UA from the engine fire up to engine shut down. UA operator is the main part of the UAS flight crew. The UAV operator plans the flight in advance, and executes the flight operation. He performs preflight, in-flight, post-flight checks and procedures, and he performs the take-off and landing from runway by maintaining contact with tower and Air Traffic Control. Moreover he performs the emergency procedures while a malfunction or an abnormal issue occurs. He should be ready for the dynamic replanning when it is needed. Furthermore he also provides coordination between the crew members and gives the final decisions related to unmanned aircraft.

Payload operator: This individual operates the payload when the UA is on the ground, at the time of takeoff and landing, and in all phases of flight operations. The payload operator is an indispensable part of the UAS flight crew, who also assists the UAV operator/Pilot in Command (PIC) by reading the checklist and helping in emergency situations. Furthermore, he attends the briefing, mission planning, mission execution, and debriefing phases with the UAV operator and the CS technician.

CS Technician: The control station (CS) technician performs the preflight and post-flight checks, executes the required procedures of CS to maintain UA functionality during the flight. In some structures, a CS technician works as a part of the maintenance technician crew. CS technician optimally work within the flight crew team, because they are capable of handling the CS emergencies quickly, and are able to attain correct solutions more efficiently during most in-flight emergency cases.

Figure 2. UV operator and payload operator in GCS during mission execution.

2. Payload Element

Payload is equipment a UA carries during the flight that is necessary to accomplish the mission. There are various types of payloads that are mounted according to the mission type. It is almost impossible to see a flying UA without a payload, with the exception of some test and training flights. Quality of the payload directly affects mission quality. Furthermore, payload and endurance of the UA has an inverse ratio; increasing the payload size and weight requires eliminating some amount of fuel, which reduces the range and endurance of the UA. Figure 3 illustrates EO/IR Payload of Heron type UA.

Figure 3. EO/IR payload (from Defense-Update, 2009)

3. Communication/Datalink Element

The UA is controlled from the ground control station by line of sight (LOS), relay and/or satellite communication (SATCOM) data link. LOS is used for low range distances, while relay and SATCOM help to extend the range and also are good for low altitude flights or flights in mountainous areas. A datalink element is necessary for communication between the UA and the ground control station (GCS). Commands to the UA, payload and sensors send via uplink, while real time information from sensors, telemetry, and video images come via downlink.

4. Control Element

a. Autopilot

The autopilot function provides self-control of the aircraft during takeoff, landing, and desired flight phases when a UA operator does not have control on the UA. Using autopilot reduces the error ratio of a UA operator during two critical times: landing and takeoff.

b. Control Station

CS is a control center of UA, such as a cockpit in an manned aircraft. Mission planning, mission execution, and data manipulation can be performed, and most importantly, UA is operated/remotely piloted from the control station. A CS can be mobile or stationary (Anderson, 2002). The CS for UAs is generally deployed on the ground, on the deck of a ship, or possibly in an airplane (Austin, 2010). Choosing the equipment, and control and monitor tools is very important for the crew members. With well-designed CS and user-friendly equipment, missions can be performed more efficiently and conveniently. Figure 4 shows a ground control station from whence operators monitor UAs.

Figure 4. Ground Control Station (from Uvision Global Aero Systems, 2011).

5. Launch and Recovery Element

There are several launch and recovery platforms. A UA may take off and land vertically from a port that has enough space or horizontally that has enough length of runway, or a catapult launching and hand-launching may be used. The latter are used for some of the Class-l categorized UAs, but their recovery type is different than their launch style. Some of the examples of recovery types include a skid or belly landing, a catchment net landing, and parachute landing (Austin, 2010). Figure 5 shows an ANKA type of UAV that uses a runway for takeoff and landing, and a hand-launching type of Raven.

Figure 5. ANKA type of UAV (left) and a hand-launching type of Raven (right) (from UAVGLOBAL, 2014; Unmanned Ground, Aerial, Sea and Space Systems, 2011).

D. CLASSIFICATIONS OF UAS

Today's unmanned aircrafts are incredibly diverse, including Nanos and giant type UAs like the Global Hawk. NATO formed a comprehensive classification to more clearly define a suitable standardization.

NATO identifies the following three categories of UAs based on their weight, type of employment, operating altitude, mission radius, and primary supported commander (Ministry of Defence & Development, Concepts, and Doctrine Centre, 2011). Table 1 summarizes this classification scheme.

Class I: This class of UAS is generally man-portable, hand-launched and operated by an individual controller, and used for small troop protection and base security. Moreover, they have a range of less than 50 km, and are typically used at low altitudes. Infrastructure is not needed for this class.

Class II: Many of these medium-sized unmanned aircrafts can be launched from a platform, but some require a runway for takeoff and landing. Normally, they have a range between 50 km and 200 km, and their tactical missions are performed at medium altitude.

Class III: Fixed-wing UAS require runways for launch and recovery, as well as greater logistical support and infrastructure. Normally, they have a range beyond 200 km, and are used for strategic and operational missions at high altitude.

Table 1. Unmanned Aircraft Classification Guide (from Great Britain et al., 2011).

Class	Category	Normal Employment	Normal Operating Altitude	Normal Mission Radius	Civil Category (UK CAA)	Example Platform
Class I <150 kg	MICRO <2 kg	Tactical Platoon, Section, Individual (single operator)	Up to 200ft AGL	5 km (Line of Sight (LOS))	Weight Classification Group (WCG) 1 Small Unmanned Aircraft (<20 kg)	Black Widow
	MINI 2-20[13] kg	Tactical Sub-Unit (manual launch)	Up to 3000ft AGL	25 km (LOS)		Scan Eagle, Skylark, Raven, DH3
	SMALL > 20 kg	Tactical Unit (employs launch system)	Up to 5000ft AGL	50 km (LOS)	WCG 2 Light Unmanned Aircraft (20><150 kg)	Luna, Hermes 90
Class II 150–600kg	TACTICAL	Tactical Formation	Up to 10,000ft AGL	200 km (LOS)	WCG 3 UAV (>150 kg)	Sperwer, Iview 250, Aerostar, Watchkeeper
Class III >600 kg	Medium Altitude, Long Endurance (MALE)[14]	Operational/ Theatre	Up to 45,000ft AGL	Unlimited (BLOS)		Reaper, Heron, Hermes 900
	High Altitude, Long Endurance (HALE)	Strategic/ National	Up to 65,000ft AGL	Unlimited (BLOS)		Global Hawk
	Strike/ Combat	Strategic/ National	Up to 65,000ft AGL	Unlimited (BLOS)		

This thesis focuses primarily on MALE types of UASs, which fly at an altitude of up to 45,000 ft. above ground level (AGL) during most operational duties. These UASs belong to class III, and generally use SATCOM data links.

Definitions proliferate with technological developments, and now include some new categories that should be considered. Austin (2010) describes Nano Air Vehicles (NAV) in the following manner.

> NAV - Nano Air Vehicles: These are proposed to be of the size of sycamore seeds and used in swarms for purposes such as radar confusion or conceivably, if camera, propulsion, and control sub-systems can be made small enough for ultra-short range surveillance.

According to Dalamagkidis, Valavanis & Piegl (2008), it is also possible to classify UA by their level of autonomy. They described *remotely piloted* as a pilot who has a pilot certificate controls the system remotely. They described *remotely operated* as a trained operator who gives the significant commands, such as go waypoints, hold, FTC (fly to coordinate), and track target. He monitors the performance of the UA. Finally, they described *fully autonomous* as the system itself does the main tasks and is able to analyze how to complete them. They noted that the UA operator "can monitor its malfunction status and take urgent actions after the occurrence of faults" (Dalamagkidis et al. p. 722).

E. APPLICATIONS OF UAVS

Unmanned aircraft systems perform many duties both in the military and civilian sectors, but most significant success come with military applications. Although there are lots of controversies using UAVs in the same airspace with manned aircrafts due to safety, it is possible to see many applications in both military and civilian sides. Disaster response, public safety, commercial deliveries, meteorological investigations, traffic monitoring, agricultural operations, fire-monitoring support and coordination, environmental and wildlife surveying, fisheries management, monitoring water pipelines, power plants, and utilities are examples of the most common civilian UAS application areas (McDowell Group, 2013). This thesis focuses on the military applications of UASs.

Military Applications: Many duties related with military and intelligence can be performed by UAVs. The following list displays the most common and well-known military applications for UAVs (Gupta, Ghonge & Jawandhiya, 2013).

- Reconnaissance and Surveillance of enemy activity
- SAR
- Deception operations
- Maritime operations (Naval fire support, over the horizon targeting, anti-ship missile defense, ship classification)
- Radar system jamming and termination
- Meteorology missions
- Route and landing reconnaissance support
- Adjustment of indirect fire and Close Air Support (CAS)
- Battle Damage Assessment (BDA)
- Radio and data relay
- Monitoring of nuclear, biological, or chemical (NBC) contamination
- Location and destruction of land mines
- Target designation and monitoring

F. WHY USE UNMANNED AIRCRAFT?

The use of unmanned aircraft systems in the military continues to grow at a rapid pace. Significant increases have occurred during the past decade of unmanned aircraft systems, primarily in ISR missions. In these missions the authorities and the decision makers understand that unmanned systems provide clear views to give correct decisions, and for the pilot it is necessary for reducing human workload, improving mission efficiency and effectiveness, minimizing the risk, and reducing the overall cost (United States & Department of Defense, 2013).

1. Benefits

Glade (2000) indicates the following benefits that make the UAS indispensable to military forces.

- UAS provide real-time information from battlefield and operation areas so that commanders and decision makers can easily determine the target and the final actions, such as whether the target is the right target, whether the target should be destroyed.

- UAS overcome human physical limitations. Acceleration (g), forces, and fatigue are not problems or considerations for the pilot.

- UAVs can be more maneuverable than manned aircraft and the endurance and effectiveness of the mission increases with UAVs. Although UAVs fly more than manned aircrafts, they consume less fuel (cost-effective).

- While the UA is flying, crew members can change after they accomplish their maximum flight time without hampering the mission.

- UAS provide operations safety to personnel, which are a first priority to armed forces and the public.

2. Roles

UAVs are necessary for today's world because, in addition to the advantages above, UAS are also better suited for some of the roles such as dull, dirty, dangerous, and covert missions than manned aircraft are. These roles are described below.

(1) Dull Roles

Extended surveillance can be very difficult and considered a dulling experience for aircrew. When they are observing a target for many hours without a break, they may often lose concentration (Austin, 2010) and become complacent. Furthermore, routine and passionless tasks, such as surveillance tasks flying over fixed targets, anti-piracy operations, and responding to communications relay, may be difficult and pointless for manned aircrafts, because these tasks require a greater degree of human oversight (Great Britain et al., 2011).

(2) Dirty Roles

Observing an area for nuclear or chemical contamination is a risky and dangerous for crew who operate a manned aircraft. UASs were employed in dirty roles between the years of 1946–1948. UASs flew into nuclear clouds to assess the damage after detonation. Such missions were too dangerous and harmful for humans (Austin, 2010; Gupta et al., 2013). In the civilian sector, unmanned aircraft may be used for reconnaissance of natural disasters, such as forest fires where smoke and flame could be harmful to the people involved (Great Britain et al., 2011). In these missions, UASs use could be intentionally terminated in a safe area once the task has been completed.

(3) Dangerous Roles

Dangerous roles can be defined as those tasks performed by a manned aircraft pilot that can cause death or bodily injury. For instance, in military operations, it is difficult and risky for a manned aircraft to penetrate heavily-defended enemy territories where reconnaissance and surveillance are necessary. Due to the lower speed and smaller size of the UAS, it is challenging to detect them via radar systems (Austin, 2010).

(4) Covert Roles

Maintaining a low profile and not alerting the enemy are inevitable rules for both military and civilian policing operations and UAVs. Using less traceable equipment is necessary to maintain these rules. If infringing the foreign country's airspace is necessary, UAS can more easily perform this covert surveillance (Austin, 2010).

3. Economic Reasons

UASs have some economic advantages over manned aircrafts. First, although it depends on the size of the UA, the manufacturing cost of the UAS is lower than the manned aircraft. Secondly, when comparing two aircraft that can be used for the same mission role, the cost of a manned aircraft exceeds that of the unmanned aircraft, which can remain over a target area for a longer period-of-time (Mailey, 2013).

UA is not a single unit. At least a control station should be needed for the operability of the system. If the cost of control station is added to that of UA (UAV + UAV control station) the total amount becomes 40–80 percent of manned aircraft cost (Austin, 2010). "For example, the Predator unit cost is \$4.5 million and the Reaper is \$11 million; however, the unit costs of an F-16 and F-15E, are \$18 million and \$31 million, respectively. A fully-armed F-16 can remain in the target area for 30 minutes before having to air refuel. A Reaper UAV, with a comparable weapon load, could orbit the area for 18–20 hours." (Schwing & Army War College, 2007, p. 11).

Second, UAS have reasonable operating costs if maintenance costs (20 percent of manned aircraft cost), fuel costs (5 percent of manned aircraft cost), and inventory cost (20 percent of manned aircraft cost) are taken into consideration (Austin, 2010).

Third, the training costs are low, and the training period takes approximately 4–7 months, compared with the expensive and 2–3 year training for manned aircrafts. The U.S. Air Force spends more than \$2.6 million to train a fighter pilot, but only \$135,000 for a UAV operator (Ricks, 2010).

G. FALLACIES

It is very hard to accept changes and new implementations. People generally tend to resist new systems and insist on the current ones which they are familiar with. In this respect, it may not be easy to adapt to new innovations in aviation culture as well and this adaption difficulty may cause people to create some fallacies. People may be inclined to ignore human influence in UAS. The following fallacies describe mental models that must be overcome.

(1) The "Unmanned" Means No Human Fallacy

Some may believe no humans are involved in the UASs, but "unmanned" does not mean an absence of 'humans' in such systems. Indeed, this fallacy ignores the fact that people fix malfunctions, operate the UAV, use payloads and monitor the real-time videos or images. Moreover, because of this assumption, human factors sometimes are neglected when an UA accident occurs (Cooke, 2006).

(2) The Human Has Been Automated "Out-of the-Loop" Fallacy

Many people believe that with advanced technology, UASs are highly automated, and thus, the risks are low to operators or pilots. In reality, when problems occur, and humans must repair equipment, there are still risks to those personnel. Automation does not always revise human tasks in a positive way. Many mishaps are associated with people who are "out-of-the-loop." Because in the operation area many things can change quickly, operators must be able to easily override the automation tasks from the GCS (Cooke, 2006).

(3) The Just Like Air Traffic Control or Manned Flight Fallacy

The "Just Like Air Traffic Control" or "Manned Flight Fallacy" comes from the idea that one UAV operator can control more than one UA simultaneously similar to air traffic controllers and piloted aircraft, and that the UA operators only work is flying the aircraft. UAV operations involve more operations than air traffic control and piloted aircraft. Maneuvering from one point to another and monitoring the UAV are the basic operations of UAS. Using different types of payloads, weapon systems, and dynamic planning are additional and distinguishing operations of unmanned aircraft systems (Cooke, 2006).

H. LITERATURE REVIEW

Since 1995, limited research and studies have analyzed human causal factors in UAS accidents. In many of the projects, Human Factors Analysis and Classification System's (HFACS) immature version for the past studies and current version for the recent studies were used to understand the reasons behind the accidents and categorize them by looking at the reasons. We will explore HFACS in the following chapter in great detail and use in our analyses. We summarize here findings from significant and specific research studies on UAS accidents.

Schmidt & Parker (1995), researched 170 unmanned aircraft mishaps between 1986 and 1993 without using a specific taxonomy, and realized that more than 50 percent of the mishaps were caused by human errors (Schmidt & Parker, 1995). Seagle (1997) analyzed the UAV mishaps by using the Unsafe Operations taxonomy that defines three main levels of human causal factors, which include unsafe supervision practices, unsafe operation conditions and unsafe action committed by the operators, and seventeen subcategories.

> Seagle reviewed 203 RQ-2 Pioneer mishaps occurring during the period of fiscal years 1986-1997 and found 103 (50.7 percent) mishaps had human causal factors and 88 (43.3 percent) mishaps were specifically associated with supervisory and aircrew causal factors. Of these 88 mishaps, 64.1 percent involved unsafe supervision of which known unsafe supervisory conditions such as inadequate supervision (e.g., training, policies, and leadership) and failure to correct known problems accounted for the largest categories. Forty-six percent involved unsafe conditions of operators, mostly aeromedical conditions and crew resource management (CRM) deficiencies. Fifty-nine percent had unsafe acts with mistakes the most common category. Seagle also noted human causal factors varied based on environmental conditions, service, and phase of flight. Unsafe conditions, particularly aeromedical conditions and CRM failures, were more common during embarked versus ashore operations. Known unsafe supervisory conditions and CRM failures were associated more with Navy than Marine Corps mishaps. The landing phase accounted for 48.9 percent of the human related mishaps with CRM failures and mistakes the most common factors. (Tvaryanas, Thompson & Constable, 2005, pp. 2–3)

Seagle recommended improving supervisory practices by understanding the existing procedures and implementing new procedures. He also mentioned that the leadership training and involvement fortify this. To deal with the unsafe conditions, which the operators confront with, Seagle advised to improve aeromedical standards and training programs in CRM (Tvaryanas, Thompson & Constable, 2005).

Ferguson (1999) created a stochastic model simulation to evaluate human factors initiatives in terms of costs incurred on the budget and how ready one is for a mission. He used taxonomy of Unsafe Operations while analyzing mishaps.

> He reviewed 228 RQ-2 Pioneer mishaps occurring during the period of fiscal years 1986–1998, but limited his analysis of causal factors to the period of fiscal years 1993–1998 when mishap reports were standardized by the Navy's aviation safety program. During the latter period, there were 93 mishaps of which 55 (59.1 percent) had human causal factors. Of these 55 mishaps, 72.7 percent involved unsafe supervision, 67.3 percent unsafe

> conditions of operators, and 63.6 percent unsafe acts. (Tvaryanas et al., 2005, p. 3)

His simulation model shows that human causal factors had a significant effect on mission readiness and had equal effect on cost as electromechanical mishaps. Ferguson concluded that "human factors should be the primary target of intervention strategies and recommended the use of simulators, implementation of improved CRM training, and stabilization of the UAV career field." (Tvaryanas et al., 2005, p. 3).

For the period 1995–2003, Manning, Rash, LeDue, Noback, and McKeon (2004), examined and categorized UAS accidents by using two approaches with data that were provided by the U.S. Army Risk Management Information. They used two approaches:

> The first approach was a variant on a methodology referred to the Human Factors Analysis and Classification System (Manning et al., 2004, p. 10).The second analysis approach was based on the accident methodology defined in Department of the Army Pamphlet 385–40, "Army accident investigation and reporting." The Army uses a "4-W" approach to accident analysis that addresses the sequence of events leading to the accident. The "4-Ws" are: 1) When did error/failure/environment factor/injury occur? 2) What happened? 3) Why did it happen? 4) What should be done about it? Human causal factors are identified during this analysis and broken down into five types of failure: Individual failure, leader failure, training failure, support failure, and standards failure. (Manning et al., 2004, p. 12)

Manning et al. (2004) found a correlation between these two approaches. According to them, Individual unsafe acts or failures were the most important, significant, and widespread human-related causal factor categories (Manning et al., 2004).

Asim, Ehsan, and Rafique (2005) also used a HFACS framework to analyze UAV accidents for human causal factors. They note that the HFACS framework is extremely useful in identification of human causal elements in UAV accidents with its four levels that are human errors. These are organizational influences, unsafe supervision, preconditions for unsafe acts, unsafe acts, and 17 subdivided categories. Moreover, they formed a proposed improvement model to reduce human causal factors from mishaps.

The result of the analysis showed that 32 percent of accidents in a sample of 56 UAV accidents are associated with human factors (Asim, et al., 2005).

Tvaryanas, et al. (2005) came up with a 10-year quantitative analysis by reviewing 221 UAS mishaps. They also benefited from HFACS while analyzing these accidents. This comprehensive study revealed that 60.2 percent of the accidents involved human causal factors. The incidence of mishaps that related to human factor was 62.2 percent, 79.1 percent, and 39.2 percent for the Navy/Marines Air Force and, Army respectively. Another significant result of this study was that the reasons for the latent failures differed between the services. “Automation, instrumentation & sensory feedback” and “channelized attention” are the general factors of errors primarily associated with the Air Force; “Organizational processes that includes procedural guidance and publication errors and training deficiencies, overconfidence, and lack of crew coordination and communication” are the main factors of errors primarily associated with the Army; and “procedural guidance and publication errors, training deficiencies, inadequate supervision policies, proficiency, vision restricted by weather conditions, control and switches, channelized attention and complacency” are the contributor factors primarily associated with the Navy (Tvaryanas, et al., 2005, pp. 6–12).

Nasir and Shi-Yin (2011) focused on investigating the causal relationship between human factors and UAV accidents by using UAV accident data in the U.S. Armed Forces. For his statistical data, he used sample data from 56 accidents, including two specific types of UAVs: the Hunter (32 accidents), and the Shadow (24 accidents). This study of a sampled 56 UAV accidents showed that 15 (47 percent) accidents of the U.S. Army Hunter UAV, and 5 (21 percent) of the Shadow UAV system were associated with human factors. In this study, specific human factors needed to be taken into account such as alerts and alarms, display design deficiencies and situational awareness, procedural errors, and skill-based errors.

I. SUMMARY

Our goal is to examine the U.S. Navy UAV accident and hazards, and by analyzing the HFACS data for a select set of mishaps. This research may be helpful when determining precautions about human error/factors, and providing situational awareness for Turkish Armed Forces decision makers to show the importance of humans behind the scenes. Although the types of unmanned aircrafts are different between Turkish Armed Forces and the U.S. Navy, the causes of human errors are often similar. This can be a useful study to understand the main human factors in the mishaps and hazards.

III. REVIEW OF THE HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM (HFACS)

A. INTRODUCTION

Experts in the U.S. Navy established HFACS to investigate and analyze human factors in accidents and incidents. Research has shown that HFACS is one of the most reliable methods to determine human errors not only in commercial accidents but also in military accidents (Wiegmann et al., 2005). HFACS systematically describes the human element in the commercial, military, and general aviation (GA) accidents. It enables better results in the investigations of the underlying causal factors in the loss of multi-million dollar projects. Wiegmann and Shappell transformed the Reason's (1990) Swiss-cheese model into a framework that evaluates the reduction in the performance of the operators leading to aviation accidents. Reason makes a connection between errors and failures in the defense of a system. He asserts that despite the fact that each system in an organization has its own overlapping defense shields, these shields are not fault free. Because active failures and latent failures or conditions may cause holes on the shield just like on a 'Swiss cheese' (Figure 6). If the holes on each layer of shields line up, error is certain. What constitutes the holes in a shield is of critical importance (Reason, 1990).

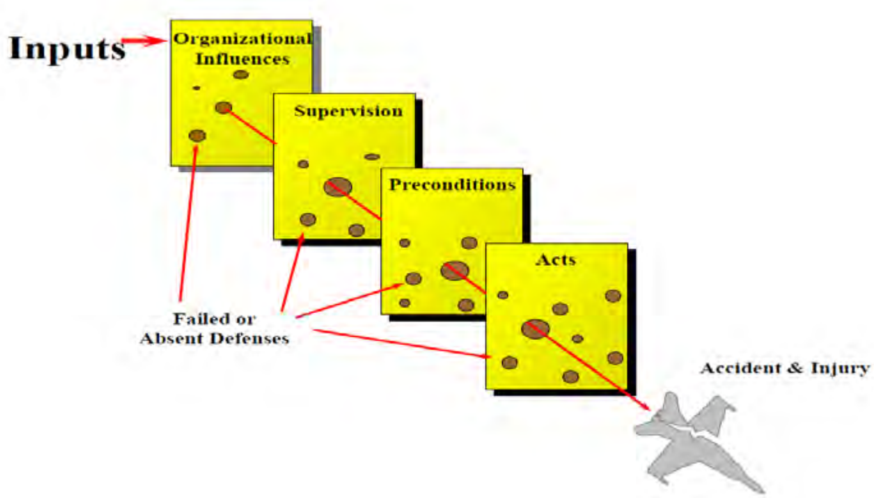

Figure 6. Reason's Swiss Cheese Model (from Naval Safety Center, 2012).

The framework of HFACS enables the investigators to determine the elements in the system that caused an unsafe situation. HFACS focuses on historical data to determine trends in UA system failures and human performance, to act proactively and reduce the probability of accidents and injury. Active and latent failures intensified in the accidents are analyzed and underlying causal factors are exposed in a specific incident (Wiegmann & Shappell, 2003).

B. THE HUMAN FACTORS ANALYSIS AND CLASSIFICATION SYSTEM

The HFACS concept relies heavily upon Reason's (1990) concept of latent and active failures, which include: Unsafe Acts, Preconditions of Unsafe Acts, Unsafe Supervision, and Organizational Influences. First acts of an operator are analyzed and then causes of these acts are determined. After which, supervisory roles are examined to determine command and control factors in the accident. Lastly, organizational issues are investigated to see the systemic picture (Naval Safety Center, 2012). Moreover, the HFACS framework consists of 19 causal factors organized by four levels, as shown in Figure 7. Despite the fact that all of the categories are equally important, one can occur in one accident, and another in a separate accident. While evaluating the causal factors, to achieve the best results, investigators should determine the cause of the given accident first, and then analyze the case associated with specific categories. Appendix A presents the HFACS taxonomy.

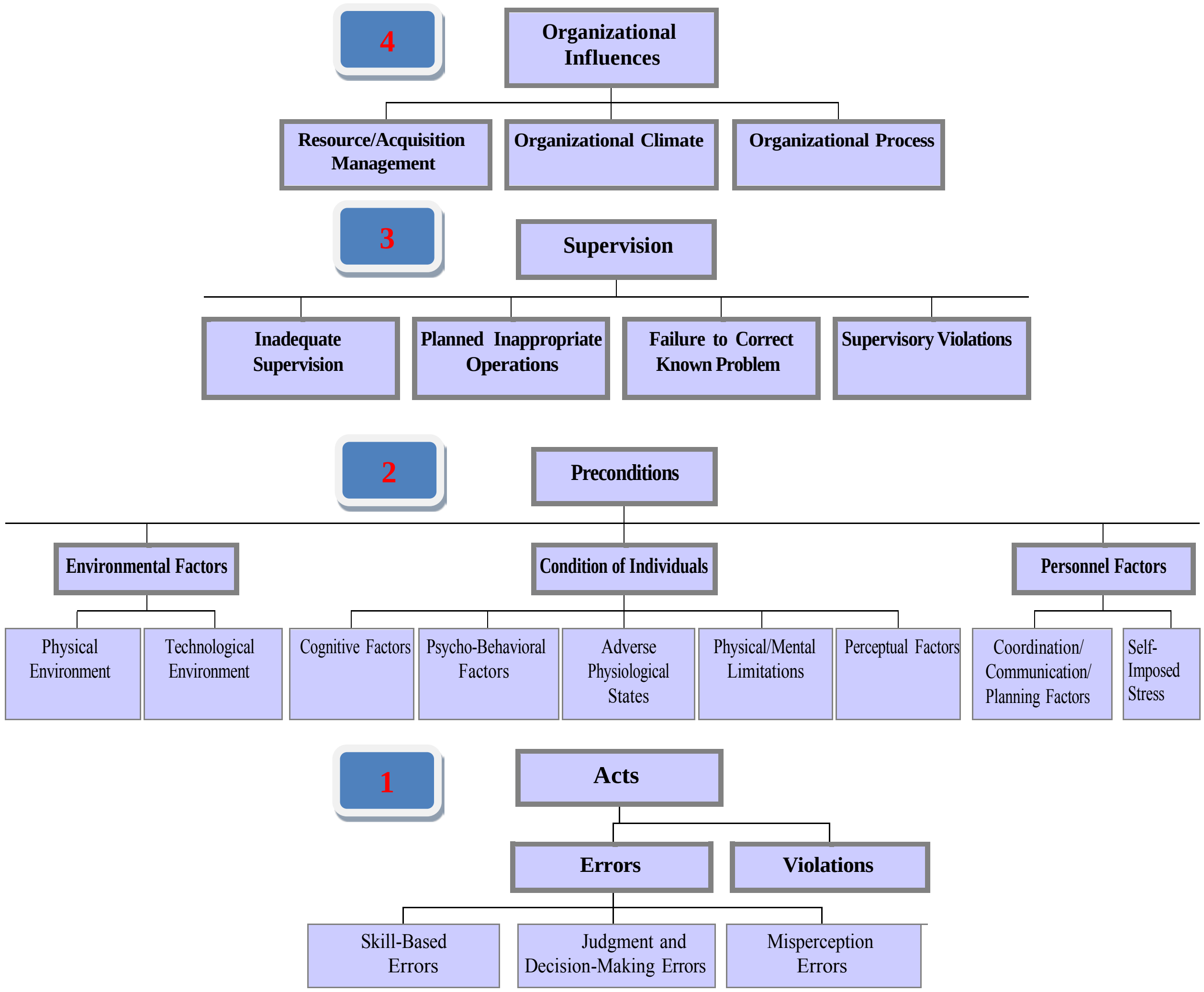

Figure 7. DOD HFACS Model (from DOD, 2005).

1. Acts

Unsafe acts can be divided into two subcategories: errors and violations. Errors constitute most of the accident database and occur because of unintentional mental and physical activities of the operators that cause the failure of predetermined results. Violations represent the intentional omission of regulations that are required for a secure flight (Reason, 1990). Figure 8 displays a detailed analysis of errors and violations by category.

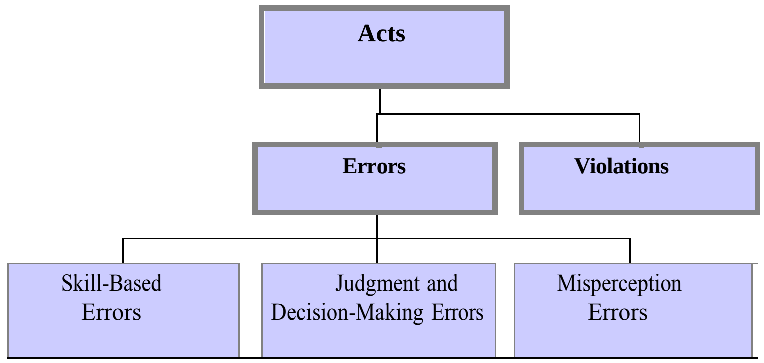

Figure 8. Subcategories of unsafe acts committed by aircrew (from DOD, 2005).

a. Errors

Errors are non-deliberate actions of operators arising from the failure in their capabilities, decision-making processes, and perceptions.

(1) Skill-Based Errors

Skill-based errors generally arise from failures in attention, memory, and technique. Not being aware of a warning light on the main board while flying close to the terrain, is an example of attention failure. Memory failure might include forgetting an item on the checklist. Finally, the way an operator controls an UAV, regardless of his experience and training, can cause an accident. Being hard on the system and overloading the engine with harsh maneuvers represent the failure in technique that can cause unintentional consequences (Shappell et al., 2000).

(2) Judgment and Decision-Making Errors

Decision errors might be honest mistakes, even if individuals are performing their best. Such errors may arise from unintentional lack of proper knowledge and poor decision making of the operator. Better plans can be devised in subsequent trials (Shappell et al., 2000).

(3) Perception Errors

Perception errors are the result of misconception or misjudgment of the operator of the aircraft's stability, ascent rate, and altitude due to harsh environmental conditions (Wiegmann et al., 2005).

b. Violations

According to Shappell and Wiegmann, violations are acts of intentional disregard for regulations and rules that are created to perform a safe flight mission, and as a result, fewer aviation accidents. There are two types of violations: routine violations and exceptional violations. Routine violations are the ones that are habitual actions of the operators and can be tolerated by the organization. Exceptional violations are ones in which operators break a basic rule and depart from authority. These kinds of violations may not be tolerated (Shappell et al., 2000).

2. Preconditions

Preconditions of unsafe acts enable the investigators to understand the causes of accidents. Because unsafe acts of operators constitute fair amount of aviation accidents, understanding their causes is fundamental in fighting against these accidents. First, preconditions for unsafe acts are divided into three sub-categories: environmental factors, condition of individuals, and personal factors. They are then divided into subdivisions for a better analysis, as shown in Figure 9 (Shappell et al., 2000).

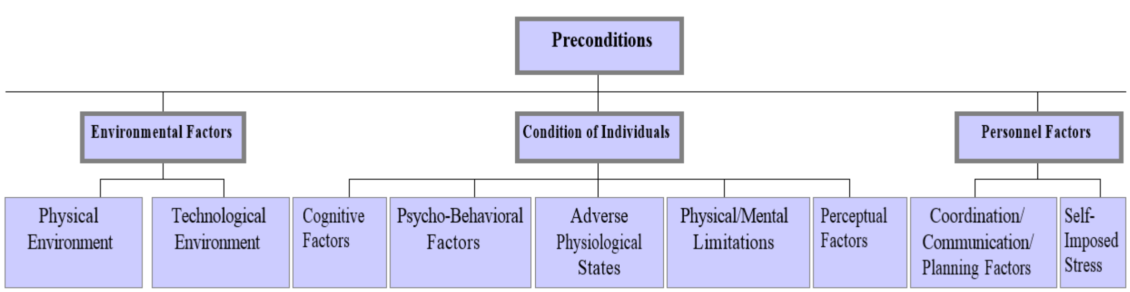

Figure 9. Subcategories of preconditions of unsafe acts (from DOD, 2005).

a. Environmental Factors

(1) Physical Environment

This category includes environmental factors such as lightening, vibration, terrain, and weather that affect the abilities of the operator and result in a mishap (DOD, 2005).

(2) Technological Environment

Technological environment affects the abilities of an operator by the design of the hardware, automation, and the structure of the workspace and may result in a mishap (DOD, 2005).

b. Conditions of Individuals

(1) Cognitive Factors

Cognitive factors affect the activities of an operator by decreasing his mental abilities and awareness in performing a job (DOD, 2005).

(2) Psycho-Behavioral Factors

Being mentally-fit is extremely important for a secure flight in aviation. Negative mental conditions severely harm the performance. Loss of situational awareness, fatigue, and lack of motivation are only some of the factors that cause adverse mental states (Shappell et al., 2000).

(3) Adverse Physiological States

Abnormal medical and physiological conditions of the operator can cause the failure of the mission or the loss of an aircraft. For example if the operator is spatially disoriented and hesitant to rely on flight instrumentation, aircraft can be lost anytime in the mission (Wiegemann, Shappell, United States, & Office of Aviation Medicine, 2001).

(4) Physical/Mental Limitations

Physical/Mental Limitations are about the lack of aptitude, opportunity, or time to adequately perform the mission. If the requirements of the mission surpass the capabilities of the operators the results can be disastrous just as in the case of flying in a stormy weather (Shappell et al., 2000).

(5) Perceptual Factors

Operators may result in an unsafe situation or an accident due to failure in their decision-making process. They should be aware of visual, auditory illusion during a mission (DOD, 2005).

c. Personnel Factors

(1) Coordination, Communication, and Planning

Lack of coordination, teamwork, and communication among the members creates management problems and may result in an unsafe situation. In aviation terms, it is about the mismanagement among pilots, air traffic personnel, or the maintenance crew on the ground. If there is a problem in the synchronization among these personnel, catastrophic results can come forward during missions (Shappell et al., 2000).

(2) Self-Imposed Stress

The readiness level of an operator for a mission directly affects the rate of human causal factors in an accident. If an operator implements all the rules and regulations to be prepared for the mission, he eliminates stress factors that create human errors. Thus, pilots/operators should plan their off-duty activities properly in order to be mentally and physically fit for the success of the mission. ‘Mission comes first’ is the motto and daily activities should be arranged for the realization of that (Shappell et al., 2000).

3. Supervision

Not all causal factors stem from the pilot or operator. There are also factors that are directly related to supervisory failures (Reason, 1990). These factors can be categorized as “inadequate supervision, planned inappropriate operations, failure to correct known problems, and supervisory violations” (p. 9), as shown in Figure 10 (Shappell et al., 2000).

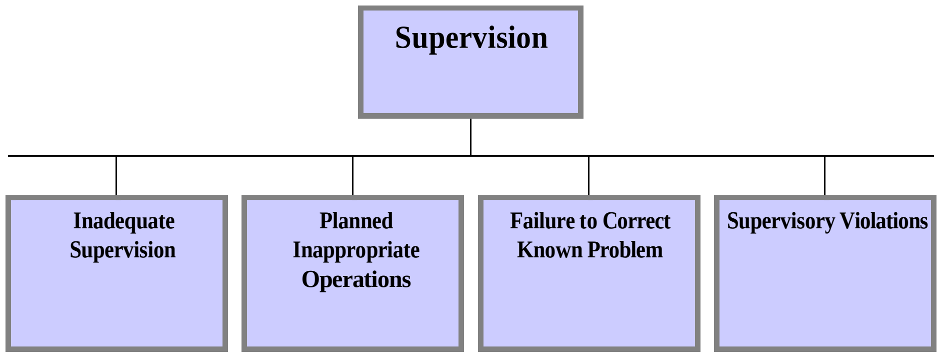

Figure 10. Subcategories of unsafe supervision (from DOD, 2005).

(1) Inadequate Supervision

For the success of the mission, the crew of a unit must be managed and supervised adequately. The role of superiors is very important in the process of training, guiding, and motivating the personnel towards the goal. For example, if the crew is not trained well and their mistakes are not corrected promptly the probability of failure in a mission will be high. Leading properly improves the skills of the operators (Shappell et al., 2000).

(2) Planned Inappropriate Operations

Before a mission, operation planners should make a thorough plan and schedule the suitable operators. Gathering necessary data and making risk management can fairly reduce the failure rate (Wiegmann et al., 2001).

(3) Failure to Correct a Known Problem

Another type of unsafe supervision is the failure to correct a known problem. These types of failures occur when the deficiencies in the system, personnel, equipment, training, or regulations are known to the superiors but are not corrected before a fatal accident takes place. For example, if a pilot is not mentally or physically fit for the mission and supervisors let him fly an aircraft, this can result in the loss of the aircraft or even the pilot himself (Shappell et al., 2000).

(4) Supervisory Violations

Supervisory violations are about the willful omission of regulations, procedures, and directives. For example, if a supervisor lets an unqualified pilot fly an aircraft, he violates a basic rule and causes the loss of the aircraft; however, these types of practices are rare in nature (Wiegmann & Shappell, 2003).

4. Organizational Influences

Not only are the performances of the operators affected by supervisory failures, but also affected by the organizational fallacies. These fallacies are grouped into three categories as resource/acquisition management, organizational climate, and organizational process (Figure 11).

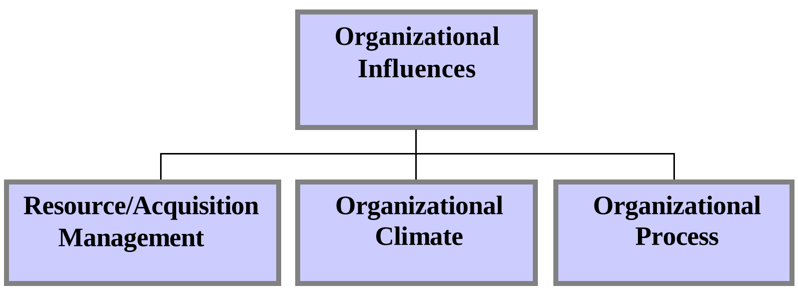

Figure 11. Subcategories of organizational influences (from DOD, 2005).

(1) Resource/Acquisition Management

Resource management is the art of allocating personnel, budget, and equipment effectively for a predetermined cause. In this regard, there is a balance between the safety level and the resource allocated to reach that level in the organizations. For example, if more money is invested on safety measures and training of the pilots, the rate of losing an aircraft will decrease. If the quality of equipment and the time allocated for operator training decreases because of sequestration on the defense expenses, the rate of aviation accidents will increase proportionally. Thus, resources should be managed wisely for the success of the mission (Wiegmann et al., 2001).

(2) Organizational Climate

Organizational climate describes the atmosphere of the organization that encompasses the relationships, policies, cultures, and command and control structure. Creating intimate relationships, sharing authority and responsibility, protecting organizational culture, being more human-centric, and being fair are all acts of shaping a peaceful atmosphere in an organization. If such issues are disregarded, people become more unconcerned about the way they perform and may cause more accidents (Shappell et al., 2000).

(3) Organizational Process

Formal processes about the regulations, applications, and decisions directly affect the way of carrying out activities of an organization. There should be standardized methods and formal rules to govern the balance between human needs and mission success. For example if the commanding officer sets up a rule by himself and change the flight hours of the pilots by increasing rest time, he may increase the risk of losing an aircraft (Wiegmann et al., 2001).

IV. ANALYSIS OF SELECT UAV ACCIDENTS

A. INTRODUCTION

The potential benefits of UAVs for a great number of applications have caught the attention of leaders in both the military and commercial sectors. Now UAVs are the new trend for many countries' military forces with their force multiplier effect that increases the effectiveness of military services dramatically, and they are popular for the civilian sector due mainly to cost factors.

The UAV, which has a remarkable advantage over manned aircraft, has been designed and manufactured with the recent technological developments. Unmanned technology rose with the need to remove the physical and mental limitations of humans. The assumption was that failure due to human error would be reduced once human involvement was reduced. However, this assumption became subject to questioning as human error accounted for more accidents in unmanned vehicles than in manned aircraft (Asim et al., 2005).

Human factors that affect UAV flight are more difficult to identify than those that affect manned flight. Since the vehicle and operator are separated, optimum human performance is hindered by a number of factors like loss of sensory cues, delays in control and communication systems, and impediments in scanning the visual surroundings of the vehicle.

The purpose of this chapter is to examine sample data related to UA mishaps and hazards, determine human error types in those mishaps and hazards, and use quantitative analysis to determine what human factor issues are most involved and what precautions should be taken.

B. U.S. NAVY ACCIDENT CLASSIFICATION SYSTEM

Accidents are classified according to financial damage and/or severity of the event. The most severe accident classification is Class A, and the least severe accident classification is Hazards (H). Table 2 illustrates the accident classes for the Navy.

Table 2. U.S. Navy Accident Classification System (Nancy B. Jones, personal communication, September 17, 2014).

Class A	Class B	Class C	Class D	Hazards (H)
Class A mishap is an accident which results in $2 million or more in property damage, destruction of an aircraft, and/or injury or illness that results in a fatality or permanent total disability.	Class B mishap is an accident which results in property damage of $500,000 or more but less than $2 million, an injury or illness that results in permanent partial disability, and/or when three or more personnel are hospitalized for inpatient care as a result of a single mishap.	Class C mishap is an accident which results in property damage of $50,000 or more but less than $500,000 and/or an injury or illness that results in one or more days away from work.	Class D mishap is an accident which results in property damage of $20,000 or more but less than $50,000 and/or an injury or illness that is greater than a first aid injury that is not otherwise classified in another category of mishap.	Hazards are any real or potential condition that can cause injury, illness, or death to personnel; damage to or loss of a system, equipment, or property; or damage to the environment.

C. DATA SOURCE

Our analysis is based on summaries of 68 UA incidents. Those summaries include detailed HFAC categories and subcategories, severity classifications of these mishaps, and flight hours occurring between fiscal year 2011 (October 1, 2010) and August 2014. The information for our analysis was obtained from the Naval Safety Center in Norfolk, Virginia. The response (formal letter) to our data request from Nancy B. Jones, Naval Safety Center Staff Attorney, is located in Appendix B, and sample data from the enclosed coding file of possible mishap factors is shown in Appendix C.

D. RESULTS

Data from the safety center was retrospectively assessed and consisted of 68 events. Figure 12 shows the distribution of the mishap classes and hazards according to severity. Of these 68 incidents, eight involved Class A type mishap, five involved Class

B type mishap, nine involved Class C type mishaps, and 46 involved Hazards that also include causal factors.

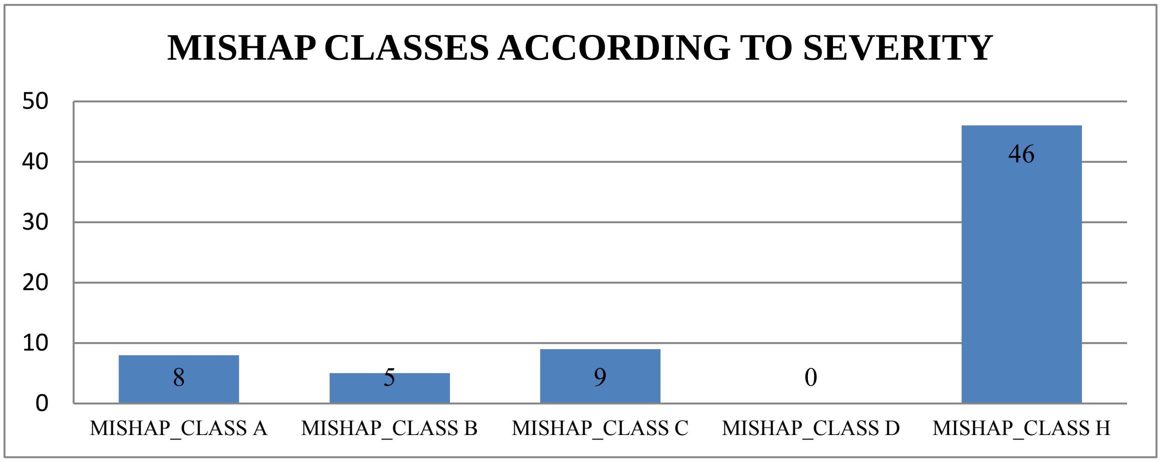

Figure 12. Number of class types of incidents.

Figure 13 represents that 287 causal factors were attributed to these 68 incidents. Of these 287 factors, 186 of them (65 percent) related to human factors, 45 of them related to material factors (16 percent), and 56 of them related to special factors (16 percent).

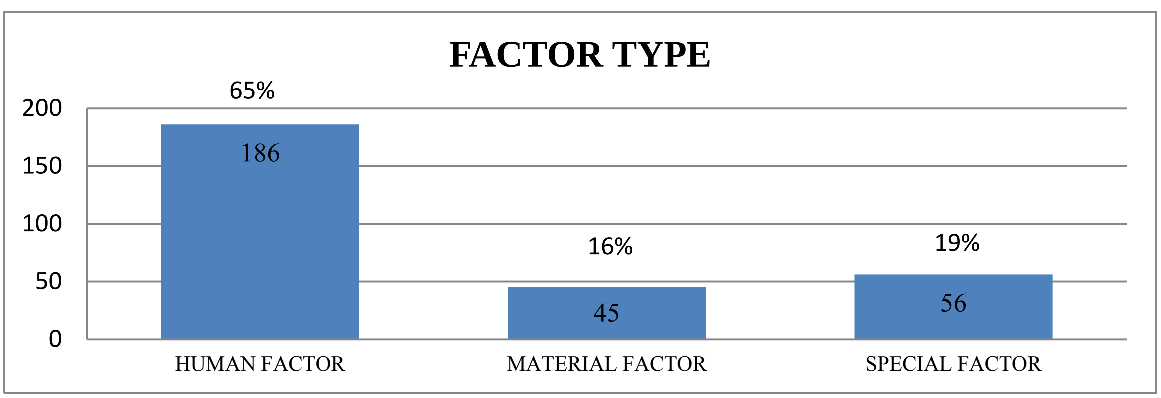

Figure 13. Breakdown of causal factors.

A single mishap may include multiple human factors, material factors, or special factors. For example, one incident, a purely mechanical mishap, which does not have any human involvement, was coded as a material factor with the use of HFACS. However, a UAV, which had failed due to mechanical factors but was made irrecoverable by human causal factors, could be coded as a human-related as well as mechanical failure; an example of the latter mishap might be engine failure, but within gliding distance of the runway (Thompson, Tvaryanas, & Constable, 2005).

HFACS data helps to identify the detailed causes for a given mishap. For example, the mishap '1318652656830' (see Appendix C) is associated with nine separate causal factors, eight human factors, and one material factor. At first glance, the mishap looks like a Heated-Throttle Plate (HTPC) failed in flight. However, if we look into the mishap, we see the human factors related to the design of the carburetor ice warning system and crew members who could not identify the presence of carburetor icing due to inadequate training.

As outlined previously, the HFACS organizes human factors along four levels of failure: a) Unsafe Acts; b) Preconditions for Unsafe Acts; c) Supervision; and d) Organizational Influences. In the following sections we provide details about these levels of failure based on the UAV mishap summaries obtained from the Naval Safety Center.

1. Unsafe Acts

Unsafe acts is the first step of investigating the mishaps, focusing on human factors in this category by answering the following question.

> What did the operator/payload operator/flight technician do, or not do, to cause the mishap (e.g., follow the wrong procedures, use the wrong button, made a bad decision, or violated the regulations)? (Naval Safety Center, 2012, p. 4)

In our sample, there are 70 total causal factors for unsafe acts. Figure 14 illustrates that 66 of the factors are associated with errors and four of them are associated with violations. A low rate in the violation category is good because the operator who causes a violation deliberately turns aside from the plan, thus breaking the rules and procedure or norms that are conveyed throughout the organization (Reason, 1990).

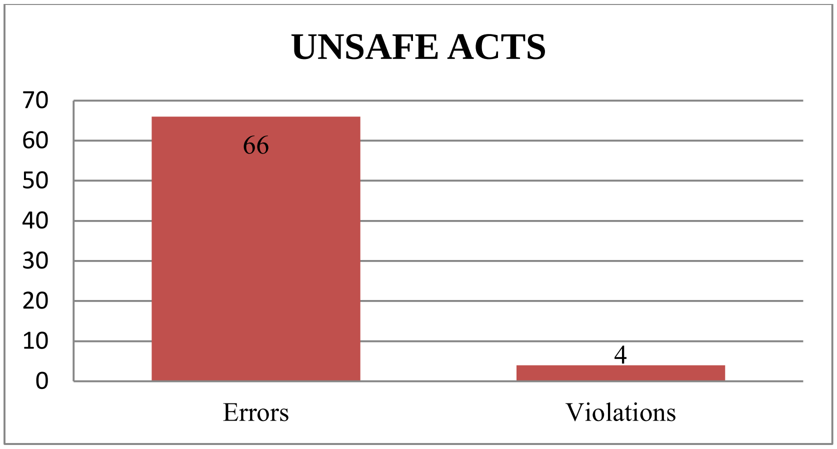

Figure 14. Breakdown unsafe acts.

Table 3 displays the subcategories of errors. 28 skill-based errors, 34 judgment and decision-making errors, and 4 perception errors are seen under error category. Procedural error, risk assessment during operations, and decision making during operations occur frequently, and should be taken into consideration to reduce human errors. Their percentages are 32 percent, 20 percent, and 17 percent, respectively.

Table 3. Breakdown of error type of human factors.

Human Factor Issue	Number of Factors	Percentage
Inadvertent Operation	2	3%
Checklist Error	3	4%
Procedural Error	21	32%
Overcontrol/ Undercontrol	1	1%
Breakdown in Visual Scan	1	1%
Skill-based Error	**28**	**41%**
Risk Assessment – During Operation	**13**	**20%**
Task Misprioritization	2	3%
Necessary Action – Rushed	3	5%
Necessary Action – Delayed	5	8%
Decision-Making During Operation	11	17%
Judgment and Decision-Making Errors	**34**	**53%**
Misperception Error	2	3%
Incorrect response to a misperception	2	3%
Perception Errors	**4**	**6%**

Procedural error is the most prevalent factor under the skilled base category, and is of concern when the operator uses the switch or control equipment inaccurately, executes the technique inaccurately, or executes the sequence of procedures in the wrong order. Procedural errors also include errors of automated systems in navigation, calculation, or operation phases. Risk assessment during operation is another main factor associated with personnel who evaluate the risks related to a special course of action insufficiently, and additionally selects the wrong course of action (Arrabito et al., 2010). An incorrect response, not acting properly for a secure flight, to an emergency is a good example of a decision-making error during the operation.

Inappropriate training, fatigue, incorrect operator selection criteria, and workload are the major reasons of these errors under unsafe acts. Even though unmanned aircraft systems are automated and computerized systems, flight experience is a need, and operators should have some aviation background, as this influences the training time and affects the training quality. Although two Air Force studies have determined that flying experience in manned aircraft is essential for Predator operators, another study found that 150–200 hours of manned flight time is needed for the pilots to gain the skills to learn basic flight maneuvers and landing with Predator (Tvaryanas et al., 2006). From experience, the personnel who have flight experience could adapt to UAVs easily, and were able to accomplish training more successfully. Moreover, simulators play a noticeable role in student training. More simulator hours make training more robust and more reliable, and help to provide appropriate training.

Generally, unmanned aircraft operators are rotated to maintain continuous operations during routine 24/7 surveillance periods. Shift work may cause fatigue, and eventually this fatigue decreases reaction times (ACC, 2014). While analyzing factors such as work source, details of shift systems, and crew rest procedures, analysts found that crew members, including pilots and sensor operators, and maintenance personnel of MQ-1 Predator, exhibited greater fatigue than manned aircraft crew members and maintenance personnel. Additionally, crew members who are stationed at a home base, and those deployed in different military bases, are equally fatigued (Arrabito et al., 2010).

Table 4. Breakdown of violation type of human factors.

Human Factor Issue	Number of Factors	Percentage
Violation - Based on Risk Assessment	1	25%
Violation - Routine/Widespread	**2**	**50%**
Violation - Lack of Discipline	1	25%

Even though the number of violations is significantly low compared with the total causal factors under unsafe acts, a high percentage (50 percent) of routine, widespread violation is the most common. Some procedures or policies can become routine and some behaviors can become habitual, but these can eventually cause a mishap or hazard, and the personnel should be aware of the results of violation. If the common violations are disregarded, these tolerances make the results serious. Personnel who violate the rules should be warned and encouraged to follow the normal procedures. Table 4 displays the breakdown of violation factors.

2. Preconditions

Figure 15 summarizes the root categories of preconditions. Personnel factors rank highest with 35 instances. Of the other two precondition factors, environmental factors have half as many incidents compared to personnel factors, and the condition of individuals (Table 5) has 26 instances. Preconditions are the second step of investigating the mishaps. The following question is tried to be answered in this category: “Why did the person do this unsafe act?”

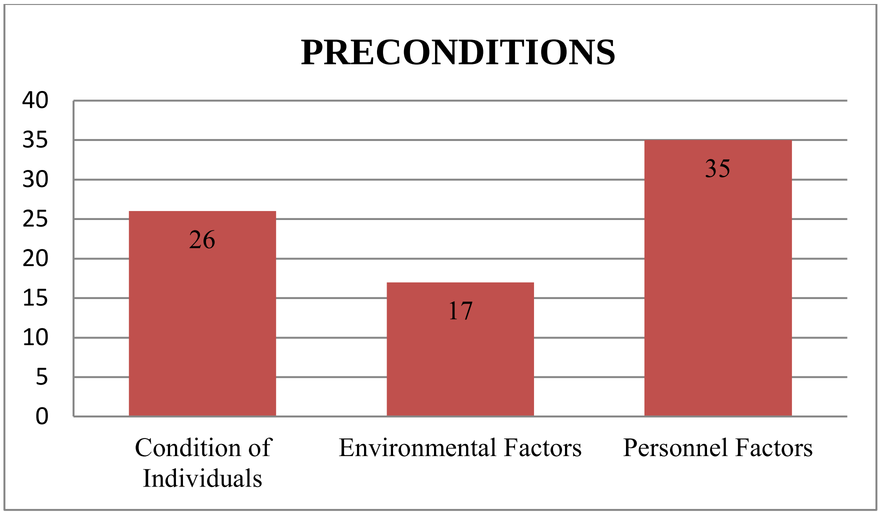

Figure 15. Breakdown of preconditions (from Naval Safety Center, 2012).

Table 5. Breakdown of condition of individuals.

Human Factor Issue	Number of Factors	Percentage
Inattention	2	7%
Channelized Attention	2	8%
Negative Transfer	2	8%
Distraction	3	11%
Checklist Interference	1	4%
Cognitive Factors	**10**	**38%**
Overconfidence	3	11%
Complacency	6	23%
Misplaced Motivation	1	4%
Excessive Motivation to Succeed	1	4%
Get-Home-It is/Get-There-It is	2	8%
Psycho-Behavioral Factors	**13**	**50%**
Misinterpreted/Misread Instrument	1	4%
Expectancy	2	8%
Perceptual Factors	**3**	**12%**

Factors associated with the conditions of individuals are divided into three main categories according to HFACS classification: cognitive, psycho-behavioral, and perceptual. When we aggregated the human factor issues into the three categories, psycho-behavioral and cognitive factors represent a significant proportion of the individual factors explaining UAV failure.

The cognitive factors that were seen in this study included two inattention, channelized attention, and negative transfers; three distractions; and one checklist interference. Increased alertness and readiness of the personnel will eventually reduce the cognitive factors in accidents. Efficient and effective scheduling and judicial workload assessment can solve these problems. For example, working six hours, taking a two-hour rest, then working another six hours, can be exhausting, and trigger attention loss for crew members. A four-hour mission in a control ground station can notably reduce the efficiency and performance to a crew, making them senseless, numb, and careless.

Psycho-Behavioral Factors include overconfidence (11 percent), complacency (23 percent), get-home-it is/get-there-it is (8 percent)—which reflects a factor when an individual or crew short-cut necessary procedures or execute poor judgment due to complete a mission or reach a result in a short period time for personal reasons—negative transfer (4 percent), misplaced motivation (4 percent), and excessive motivation to succeed (4 percent) factors (Arrabito et al., 2010).

Overconfidence and complacency are generally problems of experienced personnel. Often people who are performing the same job for a long time think that they can follow the procedures and checklist operations by heart; however, this may blind them to the hazards in advance, or miss some extremely important point when dealing with emergency situations. According to the occurrence rate, motivation-related issues are negligible for this study; however, it is important to balance the motivation level of the personnel, because both under-motivated and over-motivated individuals can easily make mistakes.

Finally, only one misinterpreted/misread instrument and two expectancy types of perceptual factors were detected in this data.

Environmental Factors refer to technological and physical environmental factors. Table 6 shows also the distribution of subcategories that related to both physical and technological environment. Table 6 clearly shows that technological environment factors are more prevalent than the physical environment.

Table 6. Breakdown of environmental factors.

Human Factor Issue	Number of Factors	Percentage
Vision Restricted by Meteorological Conditions	3	18%
Physical Environment	**3**	**18%**
Instrumentation and Sensory Feedback Systems	*6*	*35%*
Controls and Switches	1	6%
Automation	2	12%
Communications – Equipment	***5***	***29%***
Technological Environment	**14**	**82%**

Eighty-two percent of the environmental factors are associated with technological environments, such as the switches and control systems, instrumentation and sensory feedback systems, communications equipment, task factors, and automation factors. Technological factors can be reduced by design implementations and technological developments. Every new technological improvement eliminates the gaps of the existence systems. More reliable, safer, more accurate and more robust systems can be developed to reduce technological factors.

Increasing the redundancy in some of the crucial systems is one way to handle technological factors. For example, Inertial Navigation System/Global Positioning System (INS/GPS), Differential GPS (DGPS), GPS, Data link, and Dead reckoning are the five navigation systems in the Heron type of UAV. There are some sensor redundancies in making the system safe, especially in control equipment and engines. It is difficult to predict the malfunctions or defects in the system, but it is possible to be prepared for the foreseeable ones. Additionally, every mishap should be an experience for the developers and also for the users. High mishap rates during the landing and take-off phase (Lum & Waggoner, 2011) provide a change from manual to automatic take-off and landing (ATOL) systems.

Another method of dealing with technological factors is providing user-friendly software and hardware systems, as well as ground control stations. An operator uses menus to navigate the UA by entering destination coordinates or drawing the route, and uses screens to see the sensor data such as engine indicators or landing gear position. No one wants to deal with complicated menus, disturbing screens, or an uncomfortable environment; as a result, these can be the cause of severe mishaps.

Physical environment can be another problem for the UA flights, as long endurance flights can make it difficult to predict weather conditions. Weather forecasts can abruptly change over time. ATOL systems eliminate cloudy, rainy, and foggy weather conditions, and satellite communication provides advantages to UAS to land on alternate runways with good weather conditions.

Table 7 shows the breakdown of personnel factors; results show that all the personnel factors are related to coordination, communication, and planning (CCP) issues. The most significant ones are miscommunication, tasks, mission-in-progress re-planning, communicating critical information, and cross-monitoring type of factors. There are no self-imposed stress-related factors that cause accidents or hazards like inadequate physical fitness, alcohol and drug usage, supplements like nicotine or caffeine, self-medication, or inadequate rest. Some of the CCP factors are reduced through training programs related to risk management through reevaluation of changes in dynamic environments, and improvements of the standard operating procedures (SOP).

Table 7. Breakdown of personnel factors.

Human Factor Issue	Number of Factors	Percentage
Crew/Team Leadership	3	8%
Cross-Monitoring Performance	5	14%
Assertiveness	1	3%
Communicating Critical Information	6	17%
Challenge and Reply	1	3%
Mission Planning	2	6%
Mission Briefing	2	6%
Task/Mission-In-Progress Re-Planning	7	20%
Miscommunication	8	23%
Coordination, Communication, Planning (CCP) Factors	**35**	**100%**

3. Supervision

Analyzing the supervision factors is the third step in the investigation of mishaps. Generally, human factors can be identified in this category by answering questions such as: “What error did the command/supervisors make? and “What is the command’s role in this event?” (Naval Safety Center, 2012, p. 4). When supervision fails in the identification, recognition, assessment, or in controlling and mitigating the risks through the means of guidance, training, or oversight, these factors often are used during operations in environments exceeding the capabilities of mishap RPA operators (Arrabito et al., 2010).

Generally, the findings reflected that perhaps someone in the command noticed the person’s preconditions, but did not take steps to forestall a mishap, or perhaps there were guidance documents and SOP in place, but they were ambiguous or not enforced. After analyzing supervision-related factors, the command better understands where they should focus for better results in the future (Naval Safety Center, 2012).

Figure 16 shows that inadequate supervision is the major factor, and exists in 20 supervision-related incidents. Others violations displayed from highest to lowest rate are planned inappropriate operations, failure to correct known problems, and supervisory violations. Categories and subcategories are displayed in Table 8.

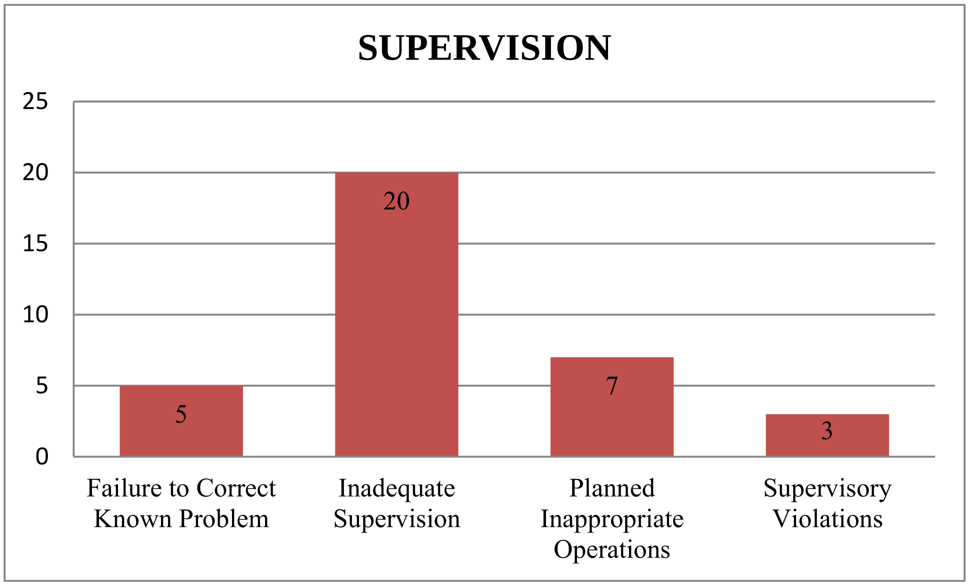

Figure 16. Breakdown of supervision-related factors.

Table 8. Breakdown of supervision subcategories.

Human Factor Issue	Number of Factors	Percentage
Personnel Management	2	6%
Operations Management	3	9%
Leadership/Supervision/Oversight Inadequate	3	9%
Local Training Issues/Programs	10	29%
Supervision – Policy	6	17%
Supervision – Lack of Feedback	1	3%
Ordered/Led on Mission Beyond Capability	1	3%
Risk Assessment – Formal	4	11%
Authorized Unnecessary Hazard	2	6%
Supervision – Discipline Enforcement (Supervisory act of omission)	1	3%
Supervision – Defacto Policy	2	6%

The most significant of these subcategories are operations management, local training issues or programs, inadequate supervision policies, formal risk assessments, and inadequate leadership and oversight.

It is the responsibility of supervisors to provide the right training opportunities, guidance, leadership, motivation, and the proper role model, regardless of how superior they are. If they fail to obtain these integral parts, the personnel tend to make more mistakes. Supervisors should be open to new policies to stimulate personnel motivation, increase their management and leadership features, and be aware of the training under their personnel (Arrabito et al., 2010).

4. Organizational Influences

Finally, organizational influences are investigated when mishaps or hazards occur. Organizational influences help to look at the organization as a whole. These factors can occur due to unclear procedures or insufficient training, or by confusing the structure in an organization. Sometimes budgetary issues may also play an important role because some equipment and items are known to be imperfect and defective, yet remain unrepaired (Naval Safety Center, 2012). Of the 51 error types of organizational influence factors, 32 of them are related to organizational processes, 11 of them are related to resource/acquisition management, and eight of them are related to organizational climate (Figure 17).

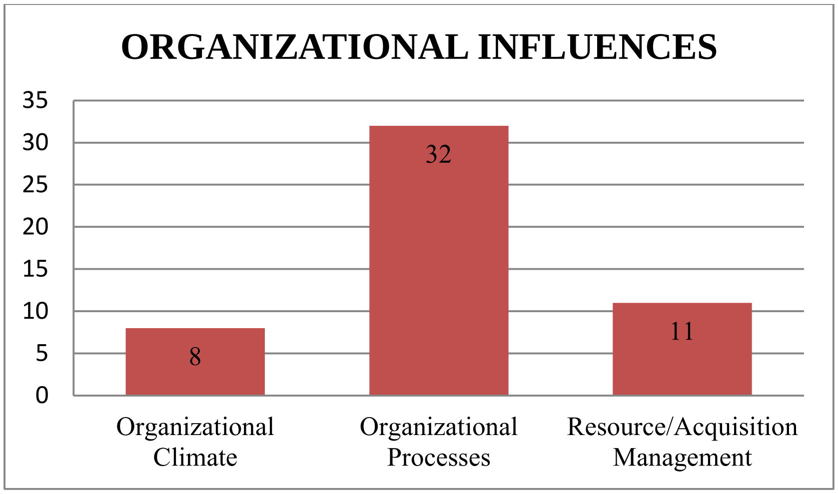

Figure 17. Breakdown of organizational influences.

Tables 9, 10, and 11 exhibit other subcategories, numbers of incidents, and the percentages of the organizational influences.

Table 9. Breakdown of organizational climate.

Human Factor Issue	Number of Factors	Percentage
Unit/Organizational Values/Culture	1	12%
Perceptions of Equipment	**4**	**50%**
Organizational Structure	3	38%

Table 9 exhibits the breakdown of organizational climate factors. Perception of equipment is the major issue in the organizational climate category. The automation capabilities and sensors of unmanned aircraft make flight procedures easier for the operator, but do not mean that the operator trusts the system and equipment all of the time. Some of the systems may not work properly during the flight or in case of emergency, and thus the operator should anticipate the potential system errors in advance.

Table 10 presents the subcategories of organizational processes. Because of their high percentages, organizational processes are major contributors. Written documents should be understandable, easy to follow, and appropriate to provide relevant procedural guidance/publications. Although there are many controversies about the training periods and the selection criteria of the UAV personnel, it is important to provide good training and necessary information to provide safe UA operations.

Procedural guidance/publications, organizational training issues/programs, and program oversight/program management are the primary focus of organizational process issues. All the procedures, programs, and trainings should be revised periodically to provide accurate procedures, more detailed programs, and more enhanced training.

Table 10. Breakdown of organizational processes.

Human Factor Issue	Number of Factors	Percentage
Ops Tempo/Workload	2	6%
Procedural Guidance/Publications	**14**	**44%**
Organizational Training Issues/Programs	**6**	**19%**
Doctrine	1	3%
Program Oversight/Program Management	**9**	**28%**

Table 11 shows the subcategories of resource/acquisition management factors. Acquisition policies and design processes are the major factors under resource/acquisition management category. Project managers and acquisition personnel should always keep in contact with users to understand the requirements clearly and to explain them to the developers who design the UA and ground control station. Additionally, to implement better designs, they should acquire and understand the lessons learned from mishap and hazard cases.

Table 11. Breakdown of resource/acquisition factors.

Human Factor Issue	Number of Factors	Percentage
Air Traffic Control Resources	1	9%
Acquisition Policies/Design Processes	**7**	**64%**
Personnel Resources	1	9%
Informational Resources/Support	2	18%

In one incident of our study, warning, caution, and advisory (WCA) messaging systems failed to alert crew in a timely manner. Further investigations should be done about this system to find the best solution to prevent issues in the future.

E. CONCLUSION

HFACS provides insight into the evaluation about mishaps or hazards. Our study revealed the importance of human factors in unmanned aircraft accidents with recent data retrieved from HFACS. Sixty-five percent of the factors were associated with human factors in our sample data of mishaps and hazards.

The major human contributing factors are procedural types of errors under skill-based error categories, such as: improper risk assessment during inappropriate decision-making operations under judgment and error categories; overconfidence and complacency factors under psycho-behavioral factors; instrumentation and sensory feedback system faults and communication equipment failures under technological environment factors; cross-monitoring performance, communicating critical information, task/mission-in-progress re-planning, miscommunication under CCP; procedural guidance/publications and program oversight/program management under organizational influences; and local training issues, programs, and supervision policies under supervision factors.

To reduce mishaps, the first approach should be to prioritize the above factors. The second step should be to find the improvement options, and the last step should be to find the possible concealed factors that cannot be identified. Using HFACS helps to identify causal factors under specific categories to prevent further hazards and further accidents with the same cause. It is also a useful system to see which factors have arisen historically, and which of them should have priority.

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V. CASE STUDIES

A. INTRODUCTION

The previous chapter provided an in-depth view and detailed categorization to identify the extent of human factors in mishaps. However, it is also important to provide homogeneity and consensus while judging and categorizing these factors because human misinterpretation and misperception can cause different categorization results while evaluating the data that related to mishap. This is a very important issue because the results of HFACS analyses are helpful for decision makers in determining how money should be allocated to decrease the occurrence of future mishaps (Bilbro, 2013).

According to the Dynamic Model of Situated Cognition, all data exists in the environment and sensor systems can only detect some of them. Users access less data than detected by the technological systems and the decision makers perceive data by using the reachable detected portion. Moreover, the decision maker’s states and traits, social circumstances, as well as personal experience influence their perception (Miller & Shattuck, 2005). This model might depict comprising the investigation reports of UAS mishaps. Mishap investigators can obtain some data associated with the mishap from the crew, meteorological station, the mishap UA (telemetry and video records) and try to come up with the reasons of the accident. However, in this process, they categorize the causal factors of the accident differently.

Although the HFACS is the most recent and common mishap analysis system that categorizes human errors in great detail, there can be a human error even in the analysis phase. In this chapter our goal is to find out whether there are some discrepancies among people’s categorization behaviors by using sample case studies.

B. CASE STUDIES

The case studies include both the executive summary and the findings from three MALE types of UA mishaps. The mishap was selected from United States Air Force Accident Investigation Board Reports database based on its plausible understanding, number of findings and level of complication. The accident reports that were used in this study were *MQ-1B, 07–3249 (17 May 2011), MQ-1B, T/N 99–3058 (26 October 2012), and MQ-1B, T/N 03–3122 (30 January 2012)* (USAF AIB Reports, 2014).

Before evaluating the findings, we present and summarize the cases. Then using HFACS categories and subcategories, we evaluate the mishap factors. We used findings from the investigation report and used DOD HFACS coding to estimate the possible factors that can cause this mishap. The purpose of our analysis here is to evaluate the mishap based on our knowledge of HFACS classification taxonomy by using significant findings and assigning a suitable category with our interpretation of them, and then comparing them with the original ones. We want to know whether these categories fit or not, and thus to see the possibility of human error in evaluation of mishap/investigation phase.

We did not look at the original investigation reports until we finished our evaluation to avoid bias. We wanted to come up with authentic results that reflect our opinions. And we use exactly the same, word for word, findings from the investigation reports to reduce the possibility of giving a different meaning to a finding, even though it can be only slightly different.

1. Case 1

a. Summary

> On 17 May 2011, at approximately 0217L, an MQ-1B, Tail Number (T/N) 07–3249, deployed from the 49 Wing at Holloman Air Force Base (AFB), NM impacted the terrain during approach and landing in Djibouti. The mishap crew (MC), deployed from the 432nd Wing, Creech AFB, NV, were recovering the mishap remotely piloted aircraft (MRPA) on an early return from an operational mission in support of Operation Enduring Freedom (OEF). The MRPA returned early due to a slow oil leak. The mishap pilot (MP) attempted to maneuver the MPRA to avoid clouds on arrival and intercepted final approach course and glidepath. However, low clouds and high humidity in the Djibouti local area obscured both IR sensors used by the crew to visually identify the runway environment at night. Additionally, inaccuracies in the LN100G INS/GPS altitude resulted in a commanded glide path approximately 420 feet below the correct glide

path. On the approach to Djibouti from the west, the terrain slopes from approximately 50 feet above mean sea level (MSL) at the touchdown zone upwards to 300 feet above MSL at four nautical miles (NM) from the end of the runway on final approach. The MP initiated a go-around at approximately 20 feet AGL at 2.4 NM on final approach, but was too late to avoid impact. The MRPA and one Air-to-Ground Missile (AGM)-114 Hellfire missile onboard were destroyed on impact at a cost of $2,983,766. There was no other government or private property damage or injuries to civilians on the ground. (MQ-1B, 07-3249, 17 May 2011, USAF AIB Reports, 2014, p. 1).

b. Significant Human-Related Findings from the Investigation

The following human-related findings are from the investigation report that raters use to match the data with the appropriate HFACS category (USAF AIB Reports, 2014, pp. 6–15).

1. UA pilot appears to perform an inadequate cross check during the final approach to Djibouti/Ambouli Airport, Djibouti. The last time the pilot mentions an altitude is departing 4,000 feet over the VOR, over 5 minutes prior to impact.

2. During the descent in the clouds, the mishap sensor operator (MSO) was not aggressive in monitoring the safety of the approach. The last mention of altitude was at 1,600 feet MSL as the aircraft was descending into Instrument Meteorological Conditions (IMC) conditions. (While there was talk of a potential go-around if the MP could not visually locate the runway, the MSO became focused on the infrared (IR) sensor picture instead of the approach information depicted on the Head-up Display (HUD)). Additionally, the MSO attempted two 2-point non-uniformity corrections to his IR picture at lower altitudes, once at just over 600 feet MSL. This caused him to essentially be blind for up for 40 seconds while the camera recalibrated in the weather which was a non-essential task at the time.

3. The MC perceived that fogging or malfunctioning sensors were the reasons of their obscured infrared HUD pictures. This misperception leads the MSO to continue attempting to correct his sensor below a safe altitude.

4. The conditions displayed on the sensors depicted low cloud decks and high humidity, causing an unclear picture on both screens. Additionally, the mishap occurred at night, causing the MP to rely solely on his infrared sensors.

5. MP focused his conscious attention on the course and glide path corrections, but failed to adequately monitor his altitude and distance from the runway.

6. Pilots on home station and during initial training do not normally fly the MQ-1 in IMC, but in simulated conditions to satisfy training requirements

7. The majority of the MQ-1 community uses 200 feet as a decision height. The decision height to be used on an instrument approach is based only on experience level of the pilot. Decision height is not an altitude chosen by the pilot, but dictated by the pilot's weather category minimums. This inaccurate decision height is taught at the formal training unit (FTU) as well.

8. The air traffic controllers at Djibouti/Ambouli Airport, Djibouti, had given incorrect altimeter settings in the past, including during the launch of the mishap sortie. The MRPA static port altitude after impact was reading 50 feet higher than the altitude that flight planning software indicated for terrain at the impact site.

9. At approximately 8,000 feet MSL, the MP checked the LN100G INS/GPS altitude against both the Novatel GPS altitude and the static port altitude and believed they were matched within 100 feet. (All three sources can be read and compared on a heads-down display (HDD), but only one is displayed in the HUD.) However, at that point, telemetry data downloaded after the accident from the GCS showed the LN100G INS/GPS altitude was actually 420 feet higher than the Novatel GPS altitude and 820 feet higher than the static port derived altitude that was displayed in the MP's HUD.

c. Our Categorization and Analysis

This mishap is a Class A type of mishap which caused $2,983,766 in damages to the aircraft and hellfire missile together. The following numbered list shows our categorization and evaluation of major findings.

1. The UA pilot should have followed the routine procedures and checked for the range to the ground. He left the altitude out during descent and crashed into the ground in the final approach. The MP would not have crashed if he had checked for the altimeter properly all through the descent. Also there is a lack of cross-monitoring performance. Because other crew members did not monitor the MP's actions during the flight and warn him to prevent the accident.

2. While there is an emergency and bad weather conditions, MSO did not focus on the most important phase of the flight. He disregarded critical landing approach and continued to reset the IR camera. Although he knew that it would take time, he misprioritized the tasks and put recalibration of IR camera in the first place. Also, we consider that this finding fits with the decision making during operation error because MSO selected the inaccurate course of action during time-constrained phase. Moreover, there should be a warning or caution message to avoid recalibrating the IR camera during approach and landing. It is not stated in the investigation report, but if there is no indication then we can say that procedural guidance/publication error is also a contributing factor along with misprioritization. However, if there is an indication in the SOP or checklist and MSO ignore it, then this refers to violation type of factors. Because it is not stated, we do not use these categories in this case's comparison part.

3. It is obvious that MSO had a misperception in exploring the reason for the obscured IR HUD pictures. The MC thought that fogging or damaged sensors caused obscured IR HUD pictures and he tried to correct the sensor below a safe altitude and caused an unsafe situation. This shows that error due to misperception is a contributing factor in the accident. He should not have done the corrective actions below the safe altitude.

4. The foggy weather, humidity, and darkness adversely affected the ability of the instrument and forced the operator to rely merely on the IR sensors. After the investigation it was realized that there was no fogging on the lenses and the sensors on the ground. This shows that obscuration on the IR instrument was caused by the severe weather conditions during the flight.

5. Channelized attention and task misprioritization are two contributing factors. Channelized attention occurs if an operator or pilot focuses on a specific subject and disregards other environmental factors leading to a hazardous situation. During the descent, the MO solely focused on the course and glide path corrections and did not pay attention to the altimeter and distance warnings. He should have monitored all the data for a secure landing. In addition, if the MO had organized his tasks properly for a secure landing and checked for the course, glide path, altitude, and distance from the runway he

would have avoided the accident. This shows that task misprioritization was a contributing factor in the accident.

6. It is necessary to be ready for the real-life conditions because UA pilots do not always have a chance to select the better option, in this case the better weather conditions. Instead of flying the MQ-1 in IMC, UA pilots who are on home station and initial training use simulators to simulate conditions to satisfy training requirements. However, real conditions and simulations do not always match. Hence, this is why local training issues/programs are a contributing factor in the accident.

7. Local training issues/programs are a contributing factor here as well. The 200-foot decision height used on an IMC approach is taught formally in the training phase, and it is generally accepted, but it has not been accepted on a written statutory basis. Pilots should be taught to use legal decision height. Otherwise, the decision height is liable to change from individual to individual depending on their experience level. Also, Leadership/Supervision/Oversight Inadequate is another contributing factor related to the 200 foot decision height. Leaders or supervisors should always investigate fallacies regarding the system and find ways to correct them. In the given case, supervisors should have directed the trainers for effective training methods and led them to bring up more inquisitive pilots.

8. The investigators found that the air traffic controllers at Djibouti/Ambouli Airport, Djibouti, had given incorrect altimeter settings in the past, including during the launch of the mishap sortie. The altimeter on the MRPA was showing faulty altitude at the crash site. This shows that unsuitable informational support provided by the airport was a contributing factor in the accident.

9. Although, at the first glance, it looks like a material error (OR004 Acquisition Policies/Design Processes) which was not evaluated in the investigation report, there can be also a human error in this. The MP checked, yet he could not see the mismatch between INS/GPS altitude and the static port altitude. It is possible that he misread the altitude, misinterpreted the altitude, or focused on another procedure while trying to read the altitudes. He could not catch the difference; we inferred a possible human factor and categorized it as the Expectancy factor. Although the pilot strongly

expected all altitude devices to match within normal limits and although he checked them, he operated under a false perception.

d. Comparison

The left column of Table 12 exhibits the original coding of human factors that are taken from investigation report and the right column shows our coding from our evaluation.

Table 12. Comparison of coding of human factors.

	INVESTIGATION REPORT	OUR EVALUATION
1	**Breakdown in Visual Scan**	**AE103 Procedural Error, PP102 Cross-Monitoring Performance**
2	**AE202 Task Misprioritization**	**AE202 Task Misprioritization AE206 Decision-Making During Operation**
3	**AE301Error Due to Misperception**	**AE301 Error Due to Misperception**
4	**PE102 Vision Restricted by Meteorological Conditions**	**PE102 Vision Restricted by Meteorological Conditions**
5	**PC102 Channelized Attention**	**PC102 Channelized Attention, AE202 Task Misprioritization**
6	**SI003 Local Training Issues/ Programs**	**SI003 Local Training Issues/ Programs**
7	**SI003 Local Training Issues/ Programs**	**SI003 Local Training Issues/ Programs, SI001 Leadership/Supervision/ Oversight Inadequate**
8	**OR008 Informational Resources/ Support**	**OR008 Informational Resources/ Support**
9	**--**	**PC506 Expectancy**

2. Case 2

e. Summary

On 26 October 2012, at approximately 2222 hours Zulu time (Z), an MQ-1B remotely piloted aircraft, tail number 99–3058, impacted the ground 53

> nautical miles southwest of Jalalabad Air Base (AB), Afghanistan, after completing a 20.4 hour surveillance mission. The MRPA was forward deployed from the 432nd Wing, Creech AFB, NV. The MRPA was operated by the 18th Reconnaissance Squadron, Creech AFB, NV. The MRPA and one air-to-ground Hellfire missile were destroyed on impact. The total damage to United States Government property was assessed to be $4,600,000 There were no injuries or damage to other government or civilian property. On 26 October 2012, at 0159Z, after normal preflight checks, the MRPA taxied and departed Jalalabad AB, Afghanistan. Handover from the Launch and Recovery Element to the Mission Control Element (MCE) was uneventful. At approximately 2200Z, the MCE completed their assigned surveillance mission and steered towards Jalalabad AB to return to base. At 2206Z, the MC, which consisted of the MP and the Mishap Sensor Operator, received a Variable Pitch Propeller (VPP) servo high temperature caution message on the HDD. This message was the first indication of a VPP problem. Eventually, the VPP failed in a manner that only allowed movement to a lower propeller pitch angle. While attempting to resolve the problem, the MP momentarily commanded the propeller pitch to an angle that produced reverse thrust. The system would not accept commands to a higher propeller pitch angle. Next, the MP shut down the engine to increase the glide distance due to the reverse thrust. The resulting loss of forward thrust prevented the MRPA from returning back to base or reaching a suitable landing location. Finally, the MP was directed to crash the MRPA, with the Hellfire missile attached, into the terrain because it would not be able to reach Jalalabad AB and there were no Forward Operating Bases nearby. The MP did as directed causing the MRPA to impact the terrain at 2222Z (MQ-1B, T/N 99–3058, 26 October 2012, USAF AIB Reports, 2014, p. 1).

f. Significant Human-Related Findings from the Investigation

The following human-related findings are from the investigation report that raters use to match the data with the appropriate HFACS category (USAF AIB Reports, 2014, p. 10).

1. Although the aircrew checklist has no notes, warnings, or cautions concerning unnecessary movements of the propeller pitch lever outside of a regime acceptable for sustained flight, the narrative section of the flight manual discusses intermittent and permanently frozen VPP servo failures.

2. The narrative section of the flight manual (TO 1Q-1(M) B-1) Propeller Servo Overheat/Servo Failure checklist addresses several possible symptoms of a failing VPP servo. The checklist itself has no notes, warnings, or cautions concerning unnecessary movements of the propeller

pitch lever outside of a regime acceptable for sustained flight. Additionally, the checklist assumes an overheating VPP servo will continuously attempt to move to match the commanded propeller pitch setting. In reality, when the propeller pitch lever is adjusted, the VPP servo will only attempt to move for three seconds.

3. In the MQ-1B simulator, an overheating VPP servo continues to draw current indefinitely and the servo heats up as a result. To stop the current and resulting overheating of the servo, crews are taught to manually move the propeller pitch lever to match the failed position of the VPP servo. Unlike the simulator, the aircraft VPP servo will only attempt to move for three seconds.

g. Our Categorization and Analysis

This mishap is a Class A type of mishap which caused a total of $4,600,000 in property damage to the aircraft and hellfire missile together. The following numbered list shows our categorization and evaluation of major findings.

1. According to investigation report, both MP and MSO are experienced and well-trained personnel. So, they are expected to be familiar with all the documents associated to UA. However, the narrative section of the checklist gives information about temporary and lasting VPP failures; MP did not refer to the flight manual narrative parts during the flight. This can be a sign of lacking technical/procedural knowledge.

2. There are some gaps in the documents associated with VPP servo failure. Although the narrative section of the flight manual explains some of the initial signs of the VPP servo failure, the checklist does not address any guidance about the propeller failure. Thus, if the operators were to check the narrative section of the checklist, they would have avoided the accident. However, they relied on the checklist itself, which is the routine procedure. Procedural Guidance/Publications should be clearer and refer to other documents if they do not touch on a specific subject.

3. The way to handle an overheating VPP servo taught in the training center was not effective to solve the propeller problem. The operators should have been trained for real-life scenarios and they should not have solely relied on simulator artifacts. Also, operators transferred their experience in the simulator to a real situation, but it did not work. Moving the propeller pitch lever to match the failed position of the VPP servo

caused the accident. On the other hand, it would work in the simulators. This analysis shows that organizational training issues/programs and negative transfers were two contributing factors in the accident.

h. Comparison

The left column of Table 13 exhibits the original coding of human factors that are taken from investigation report and the right column shows our coding from our evaluation.

Table 13. Comparison of coding of human factors.

	INVESTIGATION REPORT	OUR EVALUATION
1	**AE201 Risk Assessment – During Operation**	**PC405 Technical/Procedural Knowledge**
2	**OP003 Procedural Guidance/ Publications**	**OP003 Procedural Guidance/ Publications**
3	**OP004 Organizational Training Issues/Programs**	**OP004 Organizational Training Issues/Programs, PC105 Negative Transfer**

3. Case 3

i. Summary

On 30 January, 2012, at approximately 1000 hours Zulu (Z) time, the MRPA, a MQ-1B Predator, T/N 03–3122, operated by the 18th Reconnaissance Squadron (RS), 432nd Wing, Creech AFB, made a forced landing just outside the perimeter fence of Kandahar Air Base (AB). The crash site was an unpopulated area adjacent to the base. There were no injuries and there was no damage to other government or private property. The estimated loss is valued at $4.5 million and includes the MRPA and one AGM-114 Hellfire missile.

After normal preflight checks, the MRPA taxied and departed from a forward operating location at 0632Z. During the flight, the MCE crew, mishap crew #1 (MC1), observed abnormal engine temperature indications. The abnormal temperature indications worsened, accompanied by a significant loss of thrust and an uncommanded descent in altitude.

> MC1 began an emergency diversion to the closest suitable divert field, Kandahar AB. At 0922Z, MC1 lost video feed and positive flight control of the MRPA, but monitored flight data as it began a slow descending right-hand spiral through a full circle. At 0933Z, the Launch and Recovery Element (LRE) crew at Kandahar AB, mishap crew #2 (MC2), regained positive flight control of the MRPA and guided it to a forced landing.
>
> The Abbreviated Accident Investigation Board (AAIB) President found, by clear and convincing evidence, the cause of the mishap was a loss of coolant. During the mishap flight, the coolant pump supply line failed, releasing the engine's coolant. As the coolant supply decreased, the Cylinder Head Temperature increased excessively. Heat expansion of the cylinders permitted compressed gases from the combustion chambers to "blow by" the pistons, reducing power output and preventing sustained flight.
>
> The AAIB President found, by a preponderance of evidence, that a significant contributing factor to the loss of the MRPA was the failure to detect damage during a 60-hour engine inspection on 26 January 2012 on the coolant pump supply line and the oil cooler-to-oil pump oil line, which were routed in a manner that permitted friction chafing. Additionally, the AAIB President found, by a preponderance of evidence, that a significantly contributing factor to the loss of the MRPA was Mishap Pilot #2's (MP2) unintentional "hostile takeover" of the MRPA at 0922Z, when MP2 failed to ensure the Line-of-Sight control link transmitter was unpowered as MP2 turned the ground antenna toward the MRPA. The 1,200 feet of altitude lost in the ensuing unintentional spiral prevented a safe recovery of the crippled aircraft (MQ-1B, T/N 03–3122, 30 January 2012, USAF AIB Reports, 2014, p. 1).

j. Significant Human-Related Findings from the Investigation

The following human-related findings are from the investigation report that raters use to match the data with the appropriate HFACS category (USAF AIB Reports, 2014, pp. 13–15).

1. MC1 did not complete the Engine Overheat checklist, which directs the pilot to turn on the engine cooling fan and reduce the electrical load on the alternators. Use of the cooling fan by the MC2 resulted in a decrease in oil temperature, but by that time significant engine damage had already occurred.

2. During MP2's rack reconfiguration, MP2 rushed through loading the presets for the new aircraft and unintentionally left the LOS control link

transmitter set to ON instead of setting to OFF as directed in the setup checklists. The unrecognized assumption of control of the MRPA resulted in a wing's level, descending, rudder turn through a full circle and altitude loss of over 1,200 feet. This unintended maneuver resulted in an unrecoverable loss of altitude required for a safe landing.

3. Though aware of the engine cooling fan's capabilities, MP1 failed to turn on the engine coolant fan. Use of the cooling fan by the MC2 resulted in a decrease in oil temperature, but by that time significant engine damage had already occurred.

4. MC1 initially analyzed cockpit engine indications, referenced Technical Order data, and correctly diagnosed the situation as a loss of coolant-induced Engine Overheat. MC1 expected an Engine Failure was imminent. This expectancy led MSO1 and eventually MC1 to the false perception that the loss of altitude and additional high engine temperatures indicated an engine failure instead of realizing these were logical effects of an engine overheat. MP1 executed the Engine Failure checklist and did not resume or complete the Engine Overheat checklist. Timely execution of the Engine Overheat checklist could have reduced the damage done to the combustion system and reduced the electrical load on the engine.

5. In accordance with normal procedure, MC2 expected to have their LOS control link transmitter set to OFF and to see the LOS video from the aircraft without taking control of it. Their expectation became a false perception when they captured the LOS video signal from the aircraft and perceived that the actions taken by the aircraft were the result of MC1 satellite control inputs instead of their own. Their false perception resulted in an unrecoverable loss of altitude required for a safe landing.

6. Due to the design and capabilities of the MQ-1B Predator weapons system, any Emergency Procedure originating with an MCE will normally terminate with the LRE. Training does not adequately instruct the handoff of information to the LRE concerning the nature of emergency aircraft, status of critical systems, checklist procedures already accomplished, desired plan for the next crew to accomplished, or nonstandard hand back settings. Lack of training in time-critical emergency coordination between MCE and LRE crews led to misinformation getting to the LRE about the actual status of the aircraft and an unnecessarily elevated sense of urgency that contributed to MP2 leaving the LOS control link set to ON during his setup.

7. Mishap Maintainer 1 (MM1) and Mishap Maintainer 2 (MM2) conducted the last 60-hour inspection on the MRPA. Expert testimony states that the amount of damage present on the coolant line would have been present

during the 60-hour inspection of 26 January 2012 and that the damage should have been detected during the conduct of a normal 60-hour inspection.

8. MSO1 had under confidence in the Predator system stating multiple times that the aircraft was acting on its own accord after they lost video in the GCS. This under confidence inhibited effective troubleshooting and CRM in the cockpit because of the assumption that there was nothing to be done about the situation at hand.

k. Our Categorization and Analysis

This mishap is a Class A type of mishap which caused a total of $4,500,000 in property damage and includes the MRPA and one AGM-114 Hellfire missile together. The following numbered list shows our categorization and evaluation of significant findings.

1. Checklist error and technical/procedural knowledge are the prominent contributing factors in the given situation. Because MC1 did not complete the Engine Overheat checklist properly and thus did not use thorough information about the current operability of the MRPA. Despite the fact that the crew was experienced enough and trained well, they disregarded the importance of completing the checklist during flight. This shows that they did not absorb everything they were taught at the training center. The first things they were taught are to trust the instruments and follow the checklist.

2. In order to take the control of the MRPA, MC2 hurried to load the new data to the system and forgot to set LOS control link transmitter OFF as directed in the set-up checklists. This unintentional act of the crew caused the MRPA to lose altitude and created an unsafe situation. They had to follow the checklist and should not have panicked while taking immediate precautions. It is important to calm down when confronted with an emergency situation. Doing everything quickly and carelessly can make the things worse. That is why Necessary Action – Rushed is the contributing factor.

3. Task/Mission-In-Progress Re-Planning is the major contributing factor in the given situation. During flight, MC1 realized the abnormal temperature changes in the engine, but failed to reassess the next course of action and did not turn on the engine

coolant in time. This caused significant damage in the engine and created an unsafe situation. MC1 had to change the mission plan for a secure flight.

4. MC1 noticed the abnormal engine temperature change and thought that this would result in an engine failure. There was just an engine overheat which could have avoided or alleviated the damage if the crew had turned on the cooler in time. However, the MC1's misperception of the overheating as a failure of engine led to the loss of MRPA.

5. MC2 believed the transmitter was set to OFF. This wrong assumption together with the misperception of MC2 caused an incurable loss of altitude required for a safe landing. MC2 thought that MC1 took control of the UA and set the LOS control to OFF when they got the LOS video signal. This false perception caused an error in expectancy and they did not take action in time.

6. Training on handover procedures in time-critical emergencies is inadequate. Information sharing between the crew who give the control of the aircraft and who take the control of the aircraft did not coordinated properly. The deficiency in these fields caused the MP2 set the LOS control link ON when they intervene. However, such an intervention worsened the situation and caused the loss of the MRPA. Organizational Training Issues/Programs are the contributor factor in this finding.

7. Even though maintainers made a comprehensive routine inspection before the flight they could not detect the damage in the coolant. According to the experts there could be a problem with the engine coolant even before the operation but lack of attention by the maintainers caused the damage to go unnoticed. This shows that inattention is a contributing factor in the accident.

8. MSO1 had some concerns about the reliability of the Predator system. They experienced control problems many times in the past when they lost video connection with the system. Such bad experiences harmed their confidence in the Predators. This lack of confidence prevented them from taking necessary actions to take control of the MRPA, and they thought that it would be useless to intervene. Perceptions of Equipment is the related factor for this finding.

l. Comparison

The left column of Table 14 exhibits the original coding of human factors that are taken from investigation report and the right column shows our coding from our evaluation.

Table 14. Comparison of coding of human factors.

	INVESTIGATION REPORT	OUR EVALUATION
1	**AE102 Checklist Error**	**AE102 Checklist Error, PC405 Technical/Procedural Knowledge**
2	**AE102 Checklist Error, AE203 Necessary Action – Rushed**	**AE203 Necessary Action – Rushed**
3	**PC405 Technical/Procedural Knowledge**	**PP111 Task/Mission-In-Progress Re-Planning**
4	**PC506 Expectancy**	**PC504 Misperception of Operational Conditions**
5	**PC506 Expectancy**	**PC506 Expectancy**
6	**OP004 Organizational Training Issues/Programs**	**OP004 Organizational Training Issues/Programs**
7	**PC101 Inattention**	**PC101 Inattention**
8	**OC003 Perceptions of Equipment**	**OC003 Perceptions of Equipment**

C. CONCLUSION

Humans may see the same thing, yet each interprets the observation differently due to his own perception. These cases help us understand that human decision inconsistencies are possible in the rating/evaluating phase; the rater can differently observe, understand, and interpret the findings, and thus categorize them differently. We observe some differences after comparison of our results and the original investigation results.

These coding and categorizing differences may occur due to many factors. The most predominant factors are: lack of detail in the findings to express the right causal factors, obscure factors, oversight of coders, and/or inadequate training (Ergai, 2013). However, for these cases, we determine two main reasons. First, we do not have any experience and training about categorizing the human factors by using HFACS. Second, there are some similar and overlapping categories in which one category embraces the other. For instance, overconfidence and complacency nanocodes are both under psycho-behavioral factors and their definitions can be confusing (O'Connor, 2008). The definition of **overconfidence** is: "overconfidence is a factor when the individual overvalues or overestimates personal capability, the capability of others or the capability of aircraft/vehicle or equipment and this creates an unsafe situation" (DOD, 2005, p. 9). The definition of the **complacency** is: "complacency is a factor when the individual's state of reduced conscious attention due to an attitude of overconfidence, under-motivation, or sense that others have the situation under control leads to an unsafe situation" (DOD, 2005, p. 9). Thus, one may choose either or both of these codes to categorize the mishap

Overall, HFACS provide an in-depth classification opportunity for the raters—so much so that it is hard to find any human factor outside of HFACS scope. Sometimes we construed the findings disparately and sometimes realized that we added some factors to a specific finding. Yet all of our different interpretations and additional opinions were inside one of the HFACS categories. Hence, we can say that it can be challenging to maintain the standardization in categorizing human factors. At the same time, we can also say that HFACS is one of the most useful and reliable tools. Although there are some human influences on coding, HFACS best suits categorization and framing the human factors in UA mishaps.

VI. RESULTS

A. SUMMARY

UAVs are widely used in many fields and their popularity is on the rise. As the number of operational fields of UAVs increases, so does the potential for mishaps. Our first chapter began with the description of the issue and outlined the framework of our research. It focused on our objectives for this project and presented the research questions that guided our analysis of UAV mishaps using HFACS.

Even though there is a shift towards automation systems in commercial and military applications of aviation, the human role cannot be disregarded. In Chapter II we emphasized that reality and clarified what should be understood from UAVs. In that chapter we described the elements of UASs and summarized the roles of each element in UAV-centered operations. Classification of UAVs and operational fields of each class have been addressed as well. The popularity of UAVs is increasing and Chapter II provided information about the reasons for that modal shift toward unmanned systems. Subsequently, the chapter closed with some fallacies about UAVs. After familiarizing the reader with the terminology and overall importance of UAVs, we also examined past literature about human causal factors in UAV accidents.

HFACS systematically describes human elements in commercial, military, and general aviation (GA) accidents to achieve better results in the investigations of the underlying causal factors in the loss of multi-million dollar projects. In Chapter III we presented the HFACS framework and clarified the role of each causal factor and its subcategories. This chapter provided the baseline for analysis in later chapters. In Chapter IV, we analyzed summaries of 68 UA incidents using the detailed HFAC categories and subcategories. The mishaps occurred between 1 October 2010 and 31 August 2011. Limited data from the Naval Safety Center in Norfolk, VA, allowed us to use baseline percentages to show the most common contributor among human factors. All the data gathered from these accidents was analyzed by means of HFACS method to determine which factors are most involved and what precautions should be taken in some of the main factors. As a result, we found that 65 percent of the factors were associated with human factors in our sample data and some of them contributed to the mishaps more than others.

In Chapter V we analyzed several case summaries. Although the HFACS is the most recent and common mishap analysis system that categorizes human factors, there can be human error even in the analysis phase and differences in the interpretation and categorization of causal factors. After this study we understood that human interpretation problems in the rating/evaluating phase are possible, and necessary precautions should be taken to minimize discrepancies among the investigators.

These analyses demonstrate the importance of showing the human factor in both mishaps (as a cause) and the rating/evaluation phase. If military services categorize the factors impartially and accurately and if they focus on the main human factors that cause the majority of the mishaps, military services may allocate their resources (funding) more efficiently and effectively. Thus, military services may save time and money by addressing the most relevant and fundamental problems.

B. RECOMMENDATIONS FOR FURTHER RESEARCH

We recommend extending the scope of sample data to get more reliable and accurate results from the statistical analysis that we did in Chapter 4. In this study, we obtained data from the U.S. Naval Safety Center. The other services also have many UAVs and also some of UAs are different type, so the other services recent HFACS results also can be compared to see whether results are similar or different because every service has their own culture and has their own environment. Although they are using the same DOD HFACS frame as guidance (the category and subcategories are the same), the evaluations may be different or human causal factor percentage may be different.

We also recommend increasing the number of case studies and the rater numbers that we analyzed in Chapter 5 to get more detailed results and do a more comprehensive observation about whether there is a deviation between the raters' results. This can also give a better view of the existing of human error in the mishap evaluation and rating phase. Furthermore, we have no specific knowledge about the mishaps of unmanned aircraft (predators). We analyzed the findings from investigation reports with our knowledge and understanding; it is possible to use more experienced personnel who take specific HFACS education to categorize findings as raters.

Our other recommendation is to evaluate and categorize the mishaps by at least two different and independent teams and subsequently compare the results, and discuss and negotiate on the final factor codes to reach the most accurate result. Also, all team members can contribute their expertise and skills to establish the most accurate categorization. Taking a second look also may help diminish the discrepancies seen during the coding and categorizing.

In this study, we used U.S. data because UASs in Turkey is still growing, and there is no relevant and extended data related to UAV mishaps and hazards. We introduced the U.S. HFACS taxonomy to show and prove the existence of the human factors in unmanned aircraft accidents and to set an example that also UAV mishaps can be investigated by HFACS. It is necessary to be aware of HFACS capabilities and adopt this tool in the Turkish Armed Forces for safe flights.

Finally, our main recommendation is to implement HFACS system for Turkish military forces. This system represents an effective tool for all Turkish military services to see the most common human causal factors in UASs and provide a database and take precautions in advance. In implementing this system, it is useful to determine the trends in human performance and system failures in order to act proactively and reduce the probability of accidents and hazards. Moreover, it is possible to allocate the limited budget more conveniently by knowing the primary and more problematic factors in mishaps.

C. CONCLUSION

The number of UAV-based operations has been increasing in both commercial and military fields in recent years. Accordingly, they are finally regarded as a fundamental part of major tactical and strategic systems on the modern battlefield.

However, the increasing popularity of UAVs as a force multiplier in active combat has increased the frequency of UAV accidents dramatically, with no exception in Turkey. She has been systematically increasing her UAV inventory with national vehicles. However, transforming the force structure from manned to unmanned systems does not diminish the human role in operations. Conversely, recent research and our analysis of data taken from the Naval Safety Center in Norfolk, VA, show that human error is the leading factor (65 percent of the factors causing accidents are human-related according to our research) that caused insecure situations in aviation. Focusing on the human element while improving high-tech systems will provide more secure and more effective UAV flights.

Research has shown that HFACS is one of the most reliable methods to determine human errors in these accidents. It systematically describes human element in the commercial, military, and general aviation (GA) accidents to achieve better results in the investigations of the underlying causal factors in the loss of multi-million dollar projects. HFACS provides mishap investigators with a practical checklist-type tool by which they can identify and categorize human causal factors in accidents. It is a comprehensive application that can name correctly all kinds of human errors from an individual level to organizational level. Currently, HFACS is being widely used by the U.S. Navy, Marine Corps, Army, Air Force, and Coast Guard to determine the role of humans in aviation accidents (Shappell et al., 2000). The Turkish Armed Forces can easily adopt the system to analyze aviation accidents for better safety programs and safety measures.

In addition, HFACS enables organizations to create a database to shape the future aviation strategy. All aspects of human factors are defined with a systematic approach and results are evaluated by experts. Then occurrence rates of each human causal factor are calculated. In this way organizations learn where to invest to increase the quality of the unmanned flights. They can easily decide about the training methods of the personnel, design of the aircraft, procurement of suitable aviation personnel and organizational structure.

HFACS provides an in-depth classification opportunity for the raters; however, it is not a silver bullet that can solve the problems individually. It is the responsibility of the organizations to take the necessary measures for more safe flights in light of HFACS findings. In addition, there can be human decision inconsistencies in the rating/evaluating phase of the HFACS. The rater can differently observe, understand, and interpret the findings and accurately categorize causal factors. These coding and categorizing differences can be minimized, if not eliminated, by training programs and can turn HFACS into the optimal method to analyze human causal factors in aviation accidents.

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APPENDIX A. HFACS TAXONOMY

1. List of Unsafe Acts of Pilots and Operators (from Naval Safety Center, 2012)

ERRORS	VIOLATIONS
Skill-based Errors • Inadvertent Operation AE101 • Checklist not followed correctly AE102 • Procedure not followed correctly AE103 • Over-controlled/Under-controlled aircraft/vehicle AE104 • Breakdown in visual scan AE105 • Inadequate Anti-G straining maneuver AE106 **Judgment and Decision-Making Errors** • Risk Assessment – During Operation AE 201 (e.g., failure of Time Critical ORM) • Task Misprioritization AE 202 • Rushed a necessary action AE 203 • Delayed a necessary action AE 204 • Ignored a Caution/Warning AE 205 • Wrong choice of action during an operation AE 206 (e.g., wrong response to an emergency) **Perception Errors (due to)** • Incorrect response to a misperception AE301(e.g., visual illusion or spatial disorientation)	• Violation - Based on Risk Assessment AV001 (e.g., breaking the rules is perceived as the best solution) • Widespread/routine violation AV002 (e.g., habitual deviation from the rules that is tolerated by management) • Extreme violation-Lack of Discipline (e.g., a violation not condoned by management) AV003

2. List of Preconditions of Unsafe Acts (from Naval Safety Center, 2012)

ENVIRONMENTAL FACTORS

Physical Environment

- Icing/fog on window restricts vision PE 101
- Weather conditions restricts vision PE 102
- Vibration effect vision or balance PE 103
- Dust/smoke in workspace obstructs vision PE 104
- Windblast in workspace obstructs vision PE 105
- Cold stress PE 106
- Heat stress PE 107
- Extreme forces limits an individual's movement PE 108
- Lights of other vehicle/aircraft interfere with performance PE 109
- Noise PE 110
- Brownout (e.g., sand storm)/Whiteout (e.g., snow storm) PE 111

Technological Environment

- Seat and restraint systems problems PE 201
- Instrumentation and warning system issues PE 202
- Visibility restrictions (not weather related) PE 203
- Controls and switches are inadequate PE 204
- Automated system creates an unsafe situation PE 205
- Workspace incompatible with operation PE 206
- Personal equipment interference PE 207
- Communication equipment inadequate PE 208

CONDITIONS OF INDIVIDUALS

Cognitive Factors

- Not paying attention PC 101
- Fixation ("channelized attention") PC 102
- Task over-saturation (e.g., too much information to process) PC 103
- Confusion PC 104
- Negative transfer (e.g., using old procedures for a new system) PC 105
- Distraction PC 106
- Geographically lost (Confusion about location) PC 107
- Interference/interruption during task (Checklist Interference) PC 108

Psycho-Behavioral Factors

- Pre-existing personality disorder PC 201
- Pre-existing psychological disorder PC 202
- Pre-existing psychosocial problem PC 203
- Emotional state PC 204
- Personality style PC 205
- Overconfidence PC 206
- Pressing (e.g., pushing self or equipment too hard) PC 207
- Complacency (e.g., absence of worry) PC 208
- Not enough motivation PC 209
- Misplaced motivation PC 210
- More aggressive than necessary PC 211
- Excessive motivation to succeed (e.g., "do or die") PC 212
- "Get-home-it is"/"get-there-it is" PC 213

PERSONNEL FACTORS

Coordination/Communication/Planning Factors

- Failure of crew/team leadership PP 101
- Failure to cross-check/ back-up PP 102
- Inadequate task delegation PP 103
- Rank/position intimidation PP 104
- Lack of assertiveness PP 105
- Critical information not communicated PP 106
- Standard/proper terminology not used PP 107
- Failure to ensure communicated intentions/actions were understood and followed (Challenge and Reply) PP 108
- Mission planning inadequate PP 109
- Mission briefing inadequate PP 110
- Failure to re-assess risk and adjust to changing circumstances PP 111
- Information is misinterpreted or disregarded (Miscommunication) PP 112

Self-Imposed Stress

- Physical fitness level (inappropriate for mission demands) PP 201
- Alcohol PP 202
- Drugs/over-the-counter medication/supplements (not prescribed) PP 203
- Nutrition/diet PP 204
- Inadequate rest (self-imposed) PP 205
- Unreported Disqualifying Medical Condition PP 206

- Inappropriate response due to expectation PC 214
- Motivational exhaustion ("burnout") PC 215

Adverse Physiological States

- Effects of G forces (e.g., G-LOC) PC 301
- Effects of prescribed drugs PC 302
- Operational injury/illness PC 303
- Sudden incapacitation/unconsciousness (not due to G) PC 304
- Pre-existing physical illness/injury PC 305
- Physical overexertion PC 306
- Fatigue (sleep deprivation) PC 307
- Circadian rhythm de-synchronization (e.g., jet lag or shift work) PC 308
- Motion sickness PC 309
- Trapped gas disorders PC 310
- Evolved gas disorders (e.g., decompression sickness/bends) PC 311
- Reduced oxygen (hypoxia) PC 312
- Hyperventilation (rapid breathing) PC 313
- Inadequate adaptation to darkness PC 314
- Dehydration PC 315
- Physical task over-saturation PC 316

Physical/Mental Limitations

- Learning rate limitations PC 401
- Memory limitations PC 402
- Body size/movement limitations (Anthropometric/

	Biomechanical Limitations) PC 403 • Coordination deficiency PC 404 • Technical or procedural knowledge not retained after training PC 405 **Perceptual Factors** • Motion illusion PC 501 • Turning illusion/balance PC 502 • Visual illusion PC 503 • Misperception of changing environment PC 504 • Misinterpreted/misread instrument PC 505 • (e.g., misjudge altitude/distance/speed) • Inaccurate expectation (e.g., seeing/hearing what is expected instead of what is actually there/heard) PC 506 • Misinterpretation of auditory cues PC 507 • Spatial disorientation -- not recognized PC 508 • Spatial disorientation -- recognized PC 509 • Spatial disorientation – incapacitating PC 510 • Temporal (time) distortion PC 511

3. List of Unsafe Supervision (from Naval Safety Center, 2012)

Inadequate Supervision	Failure to Correct a Known Problem
• Command oversight inadequate SI 001 • Failed to ensure proper role-modeling SI 002 • Failed to provide proper training SI 003 • Failed to provide appropriate policy/guidance (Supervision-Policy) • SI 004 • Personality conflict with supervisor SI 005 • Lack of supervisory responses to critical information (Lack of Feedback) • SI 006 **Planned Inappropriate Operations** • Directed mission beyond personnel capabilities SP 001 • Personnel mismatch SP 002 • Selected individual with lack of current experience SP 003 • Selected individual with limited overall experience SP 004 • Selected individual with lack of proficiency SP 005 • Performed inadequate risk assessment SP 006 • Authorized unnecessary hazard SP 007	• Failed to identify/correct risky behavior SF 001 • Failed to correct unsafe practices SF 002 **Supervisory Violations** • Failure to enforce existing rules (Supervision – Discipline Enforcement) SV 001 • Allowing unwritten policies to become standard SV 002 • Directed individual to violate existing regulations SV 003 • Authorized unqualified individuals for mission SV 004

List of Unsafe Supervision (from Naval Safety Center, 2012)

Resource/Acquisition Management	Organizational Process
• Air traffic control resources are deficient OR 001 • Airfield resources are deficient OR 002 • Operational support facilities/equipment are deficient OR 003 • Purchasing or providing poorly designed or unsuitable equipment OR 004 • Failure to remove inadequate/worn-out equipment in a timely manner OR 005 • Personnel recruiting and selection policies are inadequate OR 006 • Failure to provide adequate manning/staffing resources OR 007 • Failure to provide adequate operational informational resources OR 008 • Failure to provide adequate funding OR 009 **Organizational Climate** • Organizational culture (attitude/actions) allows for unsafe mission demand/ pressure OC 001 • Inappropriate perception of promotion or evaluation procedures lead to an unsafe act OC 002 • Organizational over-confidence or under-confidence in equipment OC 003 • Impending unit deactivation or mission/equipment change leads to unsafe situation OC 004 • Organizational structure is unclear or inadequate OC 005	• Pace of ops-tempo/workload creates unsafe situation OP 001 • Organizational program/policy risks not adequately assessed, leading to an unsafe situation OP 002 • Provided inadequate procedural guidance or publications OP 003 • Organizational (formal) training is inadequate or unavailable OP 004 • Flawed doctrine/philosophy leads to unnecessary risks OP 005 • Inadequate program management leads to unsafe situation OP 006

APPENDIX B. RESPONSE LETTER

DEPARTMENT OF THE NAVY
NAVAL SAFETY CENTER
375 A STREET
NORFOLK, VA 23511-4399

5720
Ser 023/F0132
September 17, 2014

Capt Mehmet Oncu
650 Sloat Avenue
Apt 11
Monterey, CA 93940

Dear Captain Oncu:

SUBJ: YOUR FREEDOM OF INFORMATION ACT CASE 2014-NSC-133;
DON-NAVY-2014-009470

This is in response to your Freedom of Information Act (FOIA) request of August 21, 2014 requesting Human Factor (HFAC) data for unmanned aircraft accidents. Specifically, you asked for the detailed HFAC categories and subcategories (Acts, Preconditions, Supervision and Organizational Influence); for UAV mishaps of all severity classifications from fiscal year 2001 (which began on 1 October 2000) to present. You also asked for the mishap number, date, FY day, FY flight hours, and cumulative flight hours.

In my e-mail of September 5, 2014, I informed you that our UAV data collection only goes back to 2010 (FY 2011) so we are unable to provide you with information prior to that time. I also informed you that, in accordance with our safety policies and instructions, causal factors are considered privileged information and are not releasable to the public when linked to a specific mishap. Because of those limitations, I informed you that I would only be able to provide you with the UAV causal factors minus the date of the mishap and the type/model/series of the UAV.

Enclosed is a compact disk containing two Excel spreadsheets which meet the criteria of your request as modified by the restrictions explained above. The first spreadsheet, titled "ONCU-UAV flt hrs" shows the flight hour information that we have for UAVs. I must caution you that this data is not complete, a fact over which we have no control. The second spreadsheet, titled "ONCU-final data," includes the factual information within our database regarding UAV mishap HFACs. In accordance with the restrictions mentioned above, it has been redacted to exclude the dates and locations of events and the type/model/series of the involved UAV. When linked to the privileged causal factors of a mishap, these categories of information are exempt from release under 5 U.S.C. 552(b)(5). The government has a legitimate interest in withholding portions of the reports containing subjective evaluations of the mishap investigators because these investigations are conducted solely to prevent the loss of life and property. The limitation we impose on the release of personal opinions and speculation of the mishap board and endorsers encourages open, frank and honest discussion of the events surrounding mishaps which leads to safer operations for Navy and Marine Corps personnel worldwide.

The following information is provided to assist you in understanding some of the columns of data:

1. HT_ID (Column A): is a unique, computer generated identifier for the event. This number will help you see how many causal factors were attributed to each mishap. For example, the first number is repeated 26 times, from line 2 to line 27, indicating 26 separate causal factors for that event.

2. MISHAP_CLASS (Column B): Identifies the severity of the event. Class A mishaps result in $2 million or more in property damage, destruction of an aircraft, and/or injury or illness that results in a fatality or permanent total disability. Class B mishaps result in property damage of $500,000 or more but less than $2 million, an injury or illness that results in permanent partial disability, and/or when 3 or more personnel are hospitalized for inpatient care as a result of a single mishap. Class C mishaps result in property damage of $50,000 or more but less than $500,000 and/or an injury or illness that results in one or more days away from work. Class D mishaps result in property damage of $20,000 or more but less than $50,000 and/or an injury or illness that is greater than a first aid injury that are not otherwise classified in another category of mishap. Hazards, annotated as "H" in the column, are any real or potential condition that can cause injury, illness, or death to personnel; damage to or loss of a system, equipment or property; or damage to the environment.

3. HFAC_ACT_TYPE_C (Column E) is the Human Factor Act Type Code.

4. HFAC_ACT_TYPE (Column F) describes the HFAC Act Subcategory.

5. HFAC_CAUSE_C (Column G) is the Human Factor Cause code that indicates if the HFAC falls into the precondition, supervision, or organizational influences subcategory. If the code starts with:

P --> precondition
S --> supervision
O --> organizational influence

Because your request has been partially denied, you have the right to appeal this determination in writing to the designee of the Secretary of the Navy under the above statute. Your appeal, if any, must be addressed to:

Judge Advocate General (Code 14)
Navy Department
Washington Navy Yard
1322 Patterson Ave., S.E.
Suite 3000
Washington, DC 20374-5066

The appeal must be postmarked within 60 days from the date of this letter. A copy of your initial request and this partial denial letter must accompany the appeal. The appeal should be marked "FREEDOM OF INFORMATION ACT APPEAL" both on the envelope and the face of the letter. In order to expedite the appellate process and ensure full consideration of your request, your appeal should contain a brief statement of the reasons you believe this initial decision to be in error. The official responsible for the partial denial of your request is:

Kenneth J. Norton
Rear Admiral, U.S. Navy
Commander, Naval Safety Center

Your request was treated as an "all others requester" as defined by Secretary of the Navy Instruction 5720.42F dated 6 January 1999, Subject: DEPARTMENT OF THE NAVY FREEDOM OF INFORMATION ACT (FOIA) PROGRAM. There are no fees associated with the processing of your request in this instance.

If you have any questions, you may contact Mr. James Webb at (757) 444-3520 Ext 7096 or via e-mail at safe-foia@navy.mil. Please refer to case number 2014-NSC-133 when inquiring about your request.

Sincerely,

NBJones

N. B. JONES
Staff Attorney
By direction of the Commander

Enclosure

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APPENDIX C. SAMPLE DATA

HT_ID	MISHAP_CLASS	FACTOR_TYPE	STATEMENT	HFAC_ACT_TYPE_C	HFAC_ACT_TYPE	HFAC_CAUSE_C	HFAC_CAUSE
1318652656830	C	HUMAN FACTOR	MUAV aircrew failed to identify the presence of carburetor icing.	AE105	Breakdown in visual scan	OP004	Organizational (formal) training is inadequate or unavailable
1318652656830	C	HUMAN FACTOR	UASTB failed to adequately train aircrew.	AE301	Incorrect response to a misperception	OP003	Provided inadequate procedural guidance or publications
1318652656830	C	HUMAN FACTOR	UASTB failed to adequately train aircrew.	AE301	Incorrect response to a misperception	PP112	Information is misinterpreted or disregarded
1318652656830	C	HUMAN FACTOR	MUAV aircrew failed to identify the presence of carburetor icing.	AE105	Breakdown in visual scan	PP112	Information is misinterpreted or disregarded
1318652656830	C	HUMAN FACTOR	MUAV aircrew failed to identify the presence of carburetor icing.	AE105	Breakdown in visual scan	PP102	Failure to cross-check/back-up
1318652656830	C	HUMAN FACTOR	AAI Corp. improperly designed carburetor ice warning system.	AE101	Unintended operation of equipment	OR004	Purchasing or providing poorly designed or unsuitable equipment
1318652656830	C	HUMAN FACTOR	AAI Corp. improperly designed carburetor ice warning system.	AE101	Unintended operation of equipment	PP112	Information is misinterpreted or disregarded
1318652656830	C	HUMAN FACTOR	AAI Corp. improperly designed carburetor ice warning system.	AE101	Unintended operation of equipment	PE202	Instrumentation and warning system issues
1318652656830	C	MATERIAL FACTOR	Heated-Throttle Plate (HTPC) failed in flight.				
1340888831134	H	HUMAN FACTOR	Safety observers were not in position during AV load	AE202	Failure to prioritize tasks adequately		
1340888831134	H	HUMAN FACTOR	Technician failed to remove antenna IAW IETMs	AE103	Procedure not followed correctly		
1382649113056	A	HUMAN FACTOR	NAVAIR failed to provide adequate engineering information			OP003	Provided inadequate procedural guidance or publications
1382649113056	A	HUMAN FACTOR	NAVAIR accepted inadequate launch abort logic			OR004	Purchasing or providing poorly designed or unsuitable equipment
1382649113056	A	HUMAN FACTOR	NAVAIR failed to assess the risk of residual GNC integrator rate eri			OR004	Purchasing or providing poorly designed or unsuitable equipment
1382649113056	A	HUMAN FACTOR	Test point procedures did not accurately describe test point inten			SI004	Failed to provide appropriate policy/guidance
1382649113056	A	MATERIAL FACTOR	Incorrect WOS indications occurred				

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